2011-12-22

Consortium for Robotics and Unmanned Systems Education and Research (CRUSER): FY11 Annual Report

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CONSORTIUM FOR ROBOTICS AND UNMANNED SYSTEMS EDUCATION AND RESEARCH (CRUSER):

FY11 Annual Report

The Startup Year

Compiled by Lyla Englehorn, Research Associate
for CAPT Jeffrey E. Kline, USN (Ret.), CRUSER Director

NAVAL POSTGRADUATE SCHOOL

22 December 2011

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ABSTRACT

The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems (UxS) in military and naval operations. This FY11 annual report summarizes CRUSER activities in its startup year of 2011, and highlights future plans.

KEYWORDS: robotics, unmanned systems, UxS, UAV, USV, UGV, UUV

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

AAR	After Action Report
ACOS	Assistant Chief of Staff
ASW	Anti-submarine warfare
AUWS	Advanced Undersea Warfare Systems
C2	Command and control
C4	Command, control, computers and communications
CANG	California National Guard
CAVR	NPS Center for Autonomous Vehicle Research
CBE	Capability-based experimentation
CBRN	Chemical, biological, radiological, and nuclear
CENTCOM	U.S. Central Command
CFT	Cross Functional Team
CNO	Chief of Naval Operations
CRUSER	Consortium for Robotics and Unmanned Systems Education and Research
CS	Computer Sciences Department, NPS
CSAR	Combat search and rescue
CTF	Combined Task Force
DISE	Distributed Information Systems Experimentation
DNS	Distributed netted system
DoD	Department of Defense
DoN	Department of the Navy
GoG	Gulf of Guinea
GSEAS	NPS Graduate School of Engineering and Applied Sciences

IPT	Integrated Product Team
ISR	Intelligence, surveillance, and reconnaissance
JCA	Joint campaign analysis
JMMES	Joint Multi-Mission Electro-Optical System
JRSP	Joint Robotic Search Project
KSAs	Knowledge, skills, and abilities
LCS	Littoral Combat Ship
LDUUV	Large diameter UUV
LOI	Level of interoperability
LOS	Line-of-sight
MAGTF	Marine Air-Ground Task Force
MAOS	Monterey Academy of Oceanographic Sciences
MBARI	Monterey Bay Aquarium Research Institute
MBE	Mission-based experimentation
MCM	Mine counter-measures
MDA	Maritime domain awareness
METOC	Meteorological and oceanographic
MIO	Maritime interdiction operation
MISSION	Maritime In Situ Sensing Inter-Operable Network
MIW	Mine warfare
MOC	Maritime Operations Center
MRUAS	Medium range UAS
MUA	Military Utility Assessment
MUOS	Mobile User Objective System
NAG	National Assessment Group

NBVC	Naval Base Ventura County
NOC	Network Operations Center
NORTHCOM	U.S. Northern Command
NPS	Naval Postgraduate School
NSW	Naval Special Warfare
NSWC	Naval Surface Warfare Command
NUWC	Naval Undersea Warfare Command
NWDC	Navy Warfare Development Command
OA	Obstacle avoidance
ONR	Office of Naval Research
OR	Operations Research Department, NPS
PACOM	U.S. Pacific Command
POR	Program of Record
QLR	Quick Look Report
RDT&E	Research Development Test & Evaluation
RELIEF	Research and Experimentation for Local and International Emergency and First Responders
S&T	Science and technology
SATCOM	Satellite communications
SECDEF	Secretary of Defense
SECNAV	Secretary of the Navy
SME	Subject matter expert
SOF	Special Operations Forces
SPSS	Self-propelled semi-submersible
SSG	Strategic Studies Group

STEM	Science, technology, engineering, and mathematics
SWA	SOF Warfighter Assessments
SYSCOM	Systems Command
TDAs	Tactical decision aides
TNT	Tactical Network Testbed
TOC	Tactical Operations Center
TSOC	Theater Special Operations Command
UAS	Unmanned aircraft system
UAV	Unmanned aerial vehicle
UCLASS	Unmanned Carrier Launched Airborne Surveillance and Strike
USCG	U.S. Coast Guard
USIP	UAS standard interoperability profile
USMC	U.S. Marine Corps
USN	U.S. Navy
USSOCOM	U.S. Special Operations Command
USV	Unmanned surface vehicle
USW	Undersea warfare
UUV	Unmanned undersea vehicle
UxS	Unmanned system
VMU	Marine UAV Squadron
WIW	Warfare Innovation Workshop

EXECUTIVE SUMMARY

From Technical to Ethical…
From Concept Generation to Experimentation…

The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems in military and naval operations

Chartered to capture a broad array of issues related to emerging unmanned systems (UxS) technologies, CRUSER intends to encompass the successful research, education, and experimentation efforts in unmanned systems currently ongoing at NPS and across the naval enterprise. Controls, sensors, design, architectures, human capital resource requirements, concept generation, risk analysis and field experimentation are just a few interest points.

Major aligned events starting in FY11 through FY13 include concept generation workshops, technical symposia, and field experimentation to test selected technologies. However, research and education will include a broader landscape than just mission areas. This FY11 Annual Report provides a summary of activities during CRUSER's startup year in 2011, and highlights future plans.

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ACKNOWLEDGMENTS

CRUSER thanks the entire community of interest who joined us in this inaugural program year. We look forward to many successful years to come.

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I. BACKGROUND

From Technical to Ethical…
From Concept Generation to Experimentation…

The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems in military and naval operations

CRUSER intends to encompass the successful research, education, and experimentation efforts in unmanned systems (UxS) currently ongoing at NPS and across the naval enterprise. Controls, sensors, design, architectures, human capital resource requirements, concept generation, risk analysis and field experimentation are just a few interest points.

Major aligned events starting in FY11 through FY13 include concept generation workshops, technical symposia, and field experimentation to test selected technologies. However, research and education will include a broader landscape than just mission areas.

A. ORIGINS

The CRUSER program grew out of the SECNAV's UxS prioritization, and concurrent alignment of UxS research and experimentation at NPS, informally through the NPS Warfare Innovation Continuum effort.

1. Unmanned Systems (UxS) and the Navy

Summarized in Table 1 by domain, the Department of the Navy (DoN) released specific UxS long term goals and detailed new operational naval capabilities.

Table 1. Department of the Navy (DoN) UxS goals (by domain)

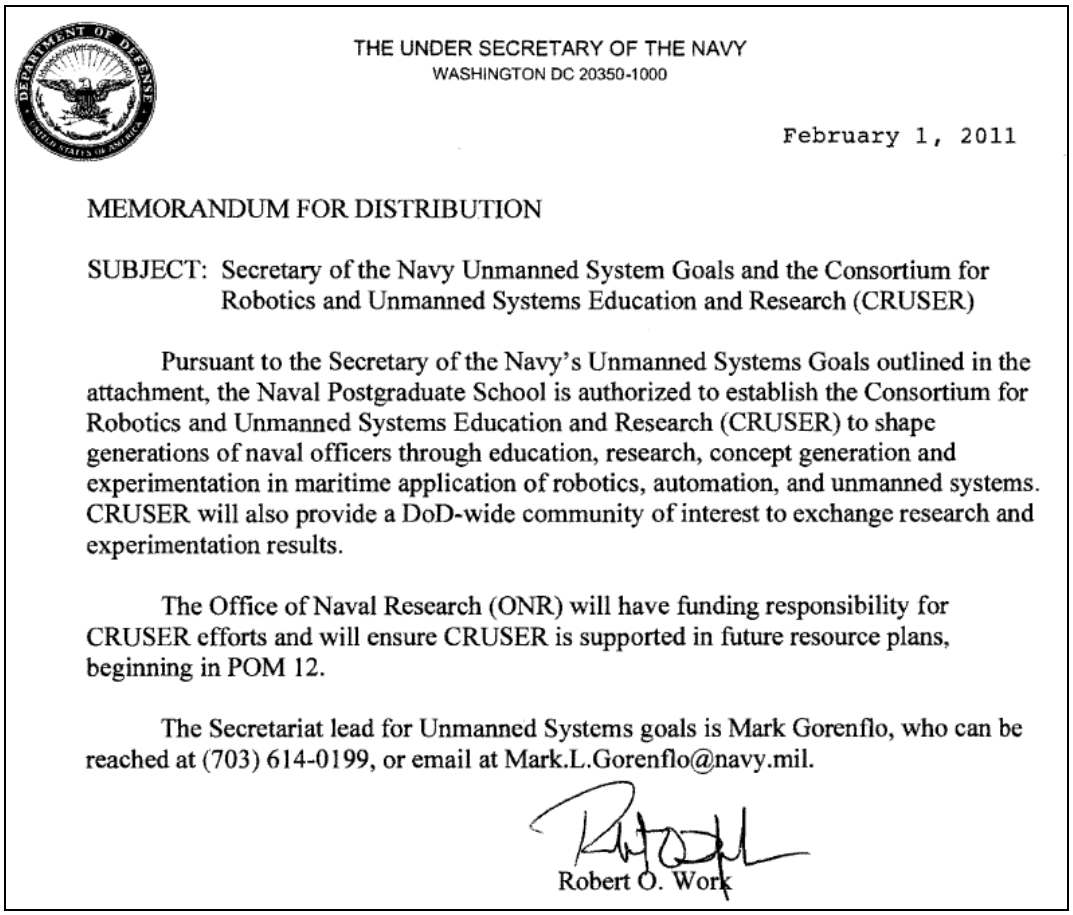
Air:	• Deploy an operational carrier capable Unmanned Carrier Launched Airborne Surveillance and Strike (UCLASS) squadron by 2020 • Develop and Deploy DoN/Joint Unmanned Aircraft System (UAS) Capabilities – develop common system components across medium range UAS (MRUAS) and Cargo UAS to achieve maximum capability for service/joint mission requirements, with a goal of achieving a common "truck" for both missions) • Promote Unmanned Aircraft System Commonality -Adopt UAS Standard Interoperability Profiles (USIP) that ensure all DoN systems have Level 3 interoperability (LOI 3) and, when appropriate, have Level 4 interoperability (WI 4): By 2018 every Ship operated systems will be controlled by common control station software. By 2020 each Marine Unmanned Aerial Vehicle Squadron (VMU) will have LOI 3 with DoN systems. By 2020 Navy and Marine Corps Group 415 Ground Control Stations will be LOI 4.
Surface and Undersea:	• Deploy Large Diameter Unmanned Undersea Vehicles (LD UUVs), from an operational UUV Squadron, on Independent missions by 2020: Commission the Squadron in 2018 to continue operational experimentation; develop tactics, techniques and procedures and begin mission planning; work to achieve UUV endurance/autonomy goals of 1) UUV capable of30 days submerged operations by 2014, 2) UUV capable of70 days submerged operations by 2016, 3) UUV capable of fully autonomous operations by 2018 • Establish a littoral combat ship (LCS) as mission-focused UxS platform in concert with Mission Module development plan: By 2018, begin forward-deploying LCS and mine counter-measures (MCM) Modules; by 2024, replace all legacy mine countermeasures ships and aircraft with LCS-based Mine Countermeasures Mission Modules incorporating unmanned mine search and sweep capability; by 2025, demonstrate USV-based ISR and fixed-site force protection capability.
Ground:	• Field an integrated Family of Robotic Systems by 2020 to augment the capabilities of the Marine Air-Ground Task Force (MAGTF)/Fleet.

Additionally, the DoN aims to support a culture that embraces UxS by establishing Navy and Marine Corps Human Capital and Training Strategy for UxS:

- By 2012, establish UxS Human Capital management processes that include accession goals, career progression milestones and tracking mechanisms.
- By 2012, develop a training strategy-to identify facilities that maximize joint efficiencies in basing and manning across the spectrum of UxS.
- By 2013 identify UxS critical Knowledge, Skills and Abilities (KSAs) required for operating UxS and develop a core curriculum to support development of those KSAs.
- By 2013, develop a strategy to Process, Exploit and Disseminate the volume of data anticipated from unmanned systems and identify the manpower and training required to support that strategy.

2. NPS as Facilitator

CRUSER will help facilitate reaching the USN and USMC UxS goals through collaboration, education, and research. In February 2011, the Under SECNAV authorized NPS to establish CRUSER "to shape generations of naval officers through education, research, concept generation and experimentation in maritime application of robotics, automation, and unmanned systems" (R. Work memorandum, *see Figure 1*).



THE UNDER SECRETARY OF THE NAVY
WASHINGTON DC 20350-1000

February 1, 2011

MEMORANDUM FOR DISTRIBUTION

SUBJECT: Secretary of the Navy Unmanned System Goals and the Consortium for Robotics and Unmanned Systems Education and Research (CRUSER)

Pursuant to the Secretary of the Navy's Unmanned Systems Goals outlined in the attachment, the Naval Postgraduate School is authorized to establish the Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) to shape generations of naval officers through education, research, concept generation and experimentation in maritime application of robotics, automation, and unmanned systems. CRUSER will also provide a DoD-wide community of interest to exchange research and experimentation results.

The Office of Naval Research (ONR) will have funding responsibility for CRUSER efforts and will ensure CRUSER is supported in future resource plans, beginning in POM 12.

The Secretariat lead for Unmanned Systems goals is Mark Gorenflo, who can be reached at (703) 614-0199, or email at Mark.L.Gorenflo@navy.mil.

Robert O. Work

Figure 1. Memorandum released by Under Secretary of the Navy, R. Work (1 February 2011) establishing CRUSER

CRUSER seeks to align efforts, both internal and external to NPS, by facilitating active means of collaboration, providing a portal for information exchange among researchers and educators with collaborative interests, and supporting innovation through directed programs of operational experimentation. Working in partnership with other organizations, CRUSER will inject a focus on robotics and unmanned systems into

existing joint and naval field experiments, exercises, and war games; as well as host specific events, both experimental and educational. The Consortium will host classified and unclassified web spaces and establish networking and collaborative environments for the community.

Furthermore, with the services' operational needs at its core, CRUSER will be an inclusive, active partner for the effective education of future military leaders and decision makers. Refining existing courses of education and designing new academic programs will be an important benefit of CRUSER, making the Consortium a unique and indispensable resource for the Navy and highlighting the educational mission of the Naval Postgraduate School.

Specific CRUSER goals are:

- Provide a source for unmanned systems employment concepts for operations and technical research;
- Provide an experimentation program to evaluate unmanned system employment concepts;
- Provide a venue for Navy-wide education in unmanned systems;
- Provide a DoD-wide forum for collaborative education, research, and experimentation in unmanned systems.

CRUSER will take a broad systems and holistic approach to address issues related to naval unmanned systems research and employment, from technical to ethical, and concept generation to experimentation. Manning requirements, human systems integration, information processing, information display, training, logistics, acquisition, development, command and control (C2) architectures, legal constraints, levels of autonomy versus mission risk are just a sample of topics for research in addition to technical research areas for these systems.

NPS is ideal as an organization to align disparate UxS efforts. Not only is NPS a leader among DoD labs in UxS research and experimentation, but has extensive established contacts throughout the global UxS community of interest. Aligned and

concurrent events in late 2010 gave the greater community of interest and engaged leadership an idea of what CRUSER could ultimately accomplish. The March 2011 CRUSER kickoff included the same concept of concurrent aligned events leveraging the campus population and environment.

B. ORGANIZATION

CRUSER is organized as a regular NPS research project except with a more extensive charter than most reimbursable projects. It has both an oversight organization and coordination team.

1. Funding and Oversight

As detailed in the previous section, CRUSER is sponsored by SECNAV. Primary funding for the start-up year of CRUSER has been provided by the Office of Naval Research (ONR), and has been projected out over the next five fiscal years. Oversight is provided on two levels: 1) an NPS advisory board, and 2) an off campus steering committee that will be formed in FY12.

2. Coordination

The five member CRUSER coordination team is led by CAPT Jeff Kline, USN (ret.) in the role of CRUSER Director. Dr. Timothy Chung is CRUSER's Director of Research and Education, and CAPT Carol O'Neal, USN (ret.) is the CRUSER Director of Innovation and Concept Development. The CRUSER administrative team consists of Lisa Trawick, CRUSER Operations Manager, and CRUSER Technical Editor, Lyla Englehorn.

II. PRIORITIES

Concept generation, education, research, experimentation, and outreach are all basic tenets for CRUSER. Specific FY11 objectives are to provide:

- a source of concept generation,
- an education venue,
- DoD-wide experimentation programs,
- and a DoD-wide forum for collaboration

A. CONCEPT GENERATION

1. Warfare Innovation Workshops (WIWs)

Innovation and concept generation are essential tenets of CRUSER, so the Warfare Innovation Workshops (WIWs) are a central element of CRUSER. War gaming has long been a fruitful endeavor for the military, and has consistently resulted in warfare innovation. The first three WIWs detailed in the following sections took place prior to the official CRUSER launch, but were integral in the creation of the program, so are included in this report.

a. Origins of the NPS WIW tradition

The NPS WIW tradition began in earnest in July 2009. The NPS Chair of Warfare Innovation, in coordination with the Navy Warfare Development Command (NWDC), developed and delivered a WIW on 16-17 July and 23-24 July 2009. The purpose of the workshop was to help NPS students develop new innovative problem solving skills and apply them to a real world challenge facing the fleet today. In addition, the workshop was to be evaluated as a resource to leverage in concept generation. This three and a half day workshop focused on countering the self-propelled semisubmersible (SPSS) drug running challenges in the 4th Fleet area of responsibility. The resulting concepts addressed all stages of the SPSS kill chain from initial

construction through the return of the SPSS pilots to Colombia. The participants explored and raised new concepts for brown water operation coordination, pattern analysis and intelligence fusion. Of particular interest was the idea of using sniffer technology for SPSS construction materials to help locate construction sites. A NPS student from the Mexican Navy planned to continue this research in his NPS thesis work based on his participation in the workshop.

b. UxS Concurrent Events, September 2010

During the 2010 NPS Enrichment Week, 20-23 September a Strategic Studies Group (SSG) WIW, a NWDC WIW, and a Robotics@NPS Workshop were held concurrently on campus. All three events were part of the NWDC sponsored yearlong Warfare Innovation Continuum and served as a kick-off for the newly organized SECNAV sponsored CRUSER. Coordination between the three events allowed all attendees to participate in joint plenary sessions on innovation and UxS, as well as NPS UxS lab tours organized by the Robotics Workshop. A forum for additional cross-workshop collaboration was provided by a Monday night "ice-breaker" for all participants sponsored by the Dean of the Graduate School of Operational and Information Sciences. Overall, participants and observers recommended this type of innovation workshop continue to be sponsored by NWDC and be scheduled quarterly at NPS or as resources allow. Estimated cost per workshop is ~$25K.

The purpose of the Strategic Studies Group (SSG) WIW conducted on September 20 – 23, 2010 was to help newly selected SSG Director's Fellows develop new innovative problem solving skills and apply them to a real world challenge facing the fleet today. This three and a half day workshop focused on concept generation for future unmanned naval systems in a C2 constrained environment. Nine NPS students representing the USN, USMC, the U.S. Coast Guard (USCG) and Chilean and Turkish navies volunteered to take on this challenge. The SSG WIW participants spent an afternoon with the SSG Deputy Director Bill Glenney for an SSG overview and then began their concept generation challenge.

Participants from both the NWDC WIW and the SSG WIW participated in a kick-off Innovation Seminar that featured NPS Chair of Innovation, Dr. Neal Thornberry. His presentation was followed by a Concept Generation Overview by NWDC Co-Chair for Warfare Innovation Doug Otte, which included a scenario presentation, assumptions and the blue force laydown. Following these briefings all participants broke into separate teams to begin their concept generation challenge. There was little senior officer involvement with the teams until the final out-briefs. Both WIWs concluded with out-briefs to Mr. Bill Glenney, SSG Deputy Director; NWDC Assistant Chief of Staff (ACOS) for Concepts, CAPT Todd Morgan; Mr. Fred Pawlowski, CAPT David Tyler and the NPS Co-Chairs for Warfare Innovation, CAPT Doug Otte and CAPT Jeff Kline. The out-briefs were held in the workshop classroom to facilitate conversation and collaboration vice auditorium-style formal presentations which proved very successful.

Overall the goals of creating a supportive environment for junior officers to innovatively address concept development and produce concepts to address unmanned naval systems were achieved. Feedback from a participant survey was both positive and constructive in all areas of the innovation construct. The participants explored and raised new concepts for unmanned naval systems in a C2 constrained future scenario. Highlights of interest included concepts for an electromagnetic enhanced limpet mine, regional terrestrial navigation systems, recharging/deploying stations for unmanned undersea vehicles (UUVs), an Unmanned Systems Warfare Commander and an ad hoc RPS architecture using tethered balloons. All concepts were provided to future WIW participants including points of contact for the upcoming war gaming course and joint command, control, computers, communications and intelligence (JC4I) course for evaluation and potential future development.

c. Advanced Undersea Warfare Systems (AUWS) WIW, December 2010

Drawing from the construct of previous workshops, RADM Rick Williams, NPS Chair of Mine and Expeditionary Warfare sponsored a WIW from 13 – 16

December 2010. This WIW focused on Advanced Undersea Warfare Systems (AUWS). RADM William's objective was two-fold: 1) focus on a critical future need and 2) provide a forum for members of the SEA 17B Cohort to participate in an innovative project with other students from across campus to bring innovative ideas into their Capstone research project. The Systems Engineering Analysis (SEA) curriculum is an interdisciplinary curriculum that provides a foundation in systems thinking, technology and operations analysis for warfighters. In lieu of a thesis, SEA cohorts conduct an interdisciplinary design project of significant importance to the Navy. This begins in the fifth quarter with a course on project management, where the project plan is built. Then SEA students analyze the need for the system, determine its operational concept, develop functional requirements, produce the system architecture, allocate the requirements among sub-systems, manage the design of the sub-systems, assure that the final design is integrated, assess any trade-offs made, and then implement and test the solution. Other students across campus may get involved in the design of the sub-systems. The project for the SEA 17B cohort was Advanced Undersea Weapons Systems which they completed in June 2011. The seven members of the cohort that were participating were divided among the three WIW teams. Their final report, brief, and presentation are available for review at http://www.nps.edu/Academics/Programs/SEA/subpages/projects/2011Spring.html.

Open to all NPS students, this three and a half day workshop focused on concept generation involving advanced undersea warfare systems (AUWS). The workshop challenge involved a technical survey of existing mine/mining technology projected to be available in 2025, followed by a determination of requirements based on a hypothetical chokepoint scenario. Following these two assessments a gap analysis was done to identify deficiencies. Specific areas addressed were endurance, communications, cost minimization, sensing, autonomy variability, on-board processing, detection avoidance, engagement, deployment and recovery.

Figure 2. RADM Rick Williams (5th from left), NPS Chair for Mine and Expeditionary Warfare with AUWS WIW participants (16 December 2010)

Fifteen USN students and two foreign national students (representing the Canadian Navy and Singaporean Navy respectively) volunteered to take on this challenge. They represented ten designators and seven different cross-campus curricula. Seven of these students were members of SEA 17B cohort whose final capstone project involves AUWS. The workshop began with a kick-off Innovation Seminar that featured NPS Chair of Innovation, Dr. Neal Thornberry. His presentation was followed by a historical overview presented by NPS Chair of Mine and Expeditionary Warfare, RADM Rick Williams, USN (ret.). The workshop challenge involving a hypothetical scenario with escalating tensions in a strategic chokepoint in 2025 and workshop guidelines was delivered by LT Jim Drennan, team lead for SEA17B. They also received briefings from subject matter experts (SMEs) which included Mr. Dave Everhart from the Naval Surface Warfare Center (NSWC), Panama City; and Professor Joe Rice from the NPS Physics Department.

Following these briefings, all participants broke into three separate teams to begin their concept generation challenge. There was little senior officer involvement with the teams until the final out-briefs. The workshop concluded with out-briefs to the RADM Rick Williams, USN (ret.), RADM Jerry Ellis, USN (ret.) Chair for Undersea Warfare, Professor Jim Eagle, SEA Chair, Professor Joe Rice, Professor John Osmundsen, Mr. Dave Everhart, and CAPT Wayne Hughes, USN (ret.) Professor of Practice in the NPS Operations Research Department. All out-briefs were held in the

workshop plenary classroom to facilitate conversation and collaboration vice auditorium-style formal presentations which proved very successful.

Overall the goals of creating a supportive environment for junior officers to innovatively address concept generation were achieved. The participants explored and raised new concepts for AUWS in a future constrained chokepoint scenario. Concept highlights interest included:

- Covert pre-deployment
- Paired Seaweb nodes
- Mini multipurpose UUVs
- SubNet
- Modular UUVs (mimicking 21" torpedoes) with ISR/acoustic and undersea communication delivery, recharging, and core modules
- Engagement UUVs with guidance, warhead and undersea comm modules
- Delivery and Attack UUvs

Specific information on all areas is addressed in the after action report on this event (*available upon request*).

d. FUNS Wargame Competition, March 2011

Sponsored by Battelle Labs, with content support from the Monterey Bay Aquarium Research Institute (MBARI) and the Naval Undersea Warfare Center (NUWC) Chair of Undersea Warfare, the objective of the Future Unmanned Naval Systems (FUNS) Wargame Competition was to develop innovative technological and operational concepts by teams of NPS students in a realistic scenario-based war game employing unmanned naval systems. Three competitive teams of military officers explored the current and expected capabilities of unmanned systems to conduct coordinated operations, with minimal human supervision, posed in a naval conflict that was set five years in the future. Autonomous systems of interest include submerged,

surfaced, airborne and space-based robots as well as advanced sensors and deployable networks. The FUNS war game thus examined the key capabilities, challenges and shortfalls of unmanned systems as a major component of fleet operations. Multiple innovative developmental possibilities, concepts of operations, conclusions and recommendations for future work were produced. Lessons learned hold broad interest for both Navy and industry stakeholders.

Figure 3. BLUE teams and organizers at the conclusion of the FUNS Wargame Competition 2011 (photo by NPS PAO photographer MC1 Rob Rubio)

Primary war game participants were NPS students who are active-duty military officers studying in a variety of degree programs. Participating faculty and invited external observers included senior evaluators and SMEs who provided relevant background briefings. The war game was conducted between NPS academic quarters during Enrichment Week 21-25 March 2011. Most information resources used for the war game were unclassified, though selected portions of the game used classified information.

Participant assessments, conclusions and recommendations for further work were released in a report to inform future NPS war games and future unmanned naval systems. Scenario setup information, student team products, and post-game evaluation analysis were also included in the FUNS Wargame Competition Final Report released in July 2011 *(available upon request*).

e. CRUSER Warfare Innovation Workshop, September 2011

The NWDC and CRUSER sponsored WIW was held 19-22 September 2011 on the campus of NPS in Monterey, California. This workshop was in direct support of the SECNAV directive that CRUSER foster the development of UxS concepts to be applied in naval operations. The results of the CRUSER WIW 2011 will serve as a basis for future CRUSER research, symposia, and experimentation. The results may also serve as an "idea" bank for the entire CRUSER community of interest. Subtitled "*Revolutionary Concept Generation from Evolutionary UxS Technology Changes*," this WIW leveraged the innovation lessons learned in previous workshops and was designed specifically to support concept development for UxS. Participants included NPS students, practicing engineers from Navy labs and industry, and visiting command representatives. They were asked to generate revolutionary concepts using rapidly evolving unmanned naval systems technologies.

The specific directive given to participants was to generate ideas and concepts for employing UxSs in dangerous and dirty environments to accomplish specific missions within the framework of a near peer scenario. Additionally, the WIW design team stressed that proposed solutions should emphasize current or programmed systems where incremental or evolutionary technical changes could have revolutionary operational effects.

The scenario was given as a framework for discussion and mission generation. The scenario, titled "*A Two Ocean War 2024*," contained potential U.S. campaign phases:

- Force Flow in
- Extended Maritime Interdiction Operations
- Establish Air Supremacy
- Establish Maritime Supremacy
- Amphibious operations
- Post Combat Phase Operations

Within this scenario, teams were asked to 1) choose "a scene in the movie" to develop a concept, 2) develop as many as the team desires (any phase, any

mission, and any technology), and then 3) brief their strongest concepts in order of strength, sharing their criteria for concept selection. For the selected concepts, teams were then asked to provide a technical description – as specific as possible using the engineering expertise provided to each team – and then articulate the strengths and weaknesses of each concept. Teams were also asked to retain a record of all their ideas for post-workshop review.

Targeted participants included NPS students and faculty currently participating in some aspect of unmanned naval systems education (class work or thesis research), but recruitment was open to all students, services and nationalities. Participant diversity has proved to be a force multiplier in supporting innovation in past WIW efforts. Additionally, junior Systems Command (SYSCOM) engineers and selected engineers from industry were invited to participate. Confirmed attendees were then divided into the following four teams:

- ***TEAM Big Dog:*** NPS students and junior SYSCOM and industry engineers
- ***TEAM Pirahna:*** NPS students, newly-selected Naval War College (NWC) Strategic Studies Group (SSG) Director Fellows, and junior SYSCOM and industry engineers
- ***TEAM Talisman:*** NPS students, newly-selected NWC SSG Director Fellows, and junior SYSCOM and industry engineers
- ***TEAM Silver Fox:*** NPS faculty, visiting command representatives and selected senior engineers from industry

Like past events, related meetings were scheduled concurrently with this workshop to enhance the experience for all participants. The official welcome and orientation for the newly selected U.S. Naval War College SSG Director Fellows was held concurrently with the CRUSER WIW. This allowed the SSG selectees to participate in the CRUSER WIW, and energized the SSG leadership team who were able to observe our process and outcomes. Additionally, CRUSER hosted a meeting on campus for the DoN UxS Crossfunctional Team (CFT) Integrated Product Team (IPT) deputies. These

concurrent events were planned to involve CFT members in the WIW program. CFT members were invited to attend both the introduction to innovation on the WIW's first day as well as the final concept out-briefs. Representatives of the CFT also delivered a presentation on Mission Engineering to the WIW participants.

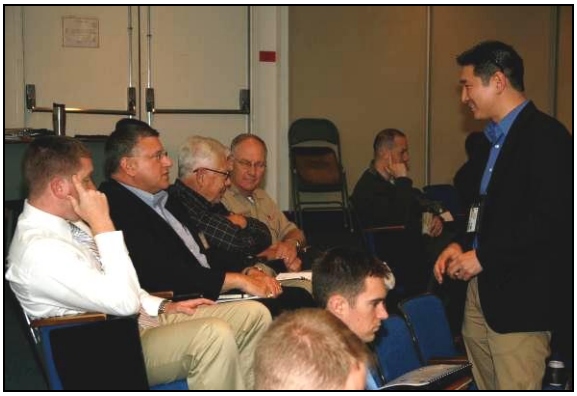


Figure 4. CRUSER Director of Research and Education Dr. Timothy Chung (standing at right), with CAPT T. Doorey (USN, ret.), CAPT W. Hughes (USN, ret.), and ADM N. Carr before the CRUSER WIW 2011 out-briefs on 22 September 2011

A final report released in October 2011 details the concepts generated by all four teams. From these innovative concepts, the CRUSER leadership team chose several and will invite industry, Navy labs, and academic researchers to demonstrate related technologies at a three day CRUSER UxS Technical Continuum in May 2012 on the NPS campus. The five concept areas under consideration include counter unmanned aerial vehicle (UAV); information assurance; intelligence, surveillance, and reconnaissance (ISR); knowledge management/data management; and non-kinetic strike.

However, the diversity of ideas presented in the final report is of value to all government, industry, and academic personnel interested in UxS applications. Each team was asked to capture all their ideas, regardless of their evaluation of their merit. These additional concepts were all included in an appendix of the CRUSER WIW 2011 After Action Report released in October 2011 (*available upon request*).

Two emergent outcomes of the CRUSER WIW 2011 that are not necessarily related to concept generation, but are in line with CRUSER's mandate, were 1) the advancement of general UxS knowledge among the participants; and 2) a greater

appreciation for the technical viewpoints for officers, or the operational viewpoint for engineers. The information interchange and relationship building that occurred during this event are characteristic of the WIW venue, and also support CRUSER's overall intent.

2. Class projects

Reaching back to the Winter Quarter 2011 and beginning in earnest with the Spring Quarter 2011, CRUSER began to align UxS related class projects across the NPS campus. CRUSER leadership also researched related coursework at the Naval Academy and the Naval War College

a. Search Theory and Detection, WINTER 2011

Students in this course, Search Theory and Detection (OA3602) investigated the operational applications of probability modeling, stochastic processes, optimization, statistical analysis, and decision making as applied to the theory of search. Topics included:

- Characterization of detection devices
- Use and interpretation of sweep widths and lateral range curves
- Models of surveillance fields, barriers, tracking and trailing
- Measures of effectiveness of search-detection systems
- Allocation of search efforts
- Sequential search
- Introduction to the statistical theory of signal detection

The increase in information-gathering and target search tasks using unmanned systems has facilitated a resurgence of analytic models for efficient search, requiring operational analysis of sensor capabilities, theoretical bounds on performance, and probabilistic models for search performance.

An example of the integration between unmanned systems and search theory disciplines is represented by the "Joint Robotic Search Project," bridging this OA3602 course with a Computer Sciences (CS) department course in robotic algorithms. With the increasing relevance of autonomous systems across all Services, the recently re-invented Advanced Robotic Systems course offered by the NPS CS department provides NPS students with an opportunity to learn about numerous fundamental principles and algorithms for robot systems.

Enhancing the educational experience is the laboratory component of the class, which uses a ground robot equipped with a laser range-finding (a.k.a. LIDAR) sensor. Students learn the theory behind path planning, obstacle avoidance, localization, and more, and immediately put to practice in lab projects implementing these algorithms in the robot control software. Some of the fundamental topics covered include:

- Path Planning: *"how to get from point A to point B"*
- Obstacle Avoidance: *"how to not run into things"*
- Localization: *"how do I know exactly where I am"*
- Mapping: *"how to navigate in unknown environments"*
- Target Tracking: *"how to follow a moving object"*
- Coverage/Search: *"how to cover and search an area"*

The capstone project was a joint final project, entitled "Joint Robotic Search Project," (JRSP) between the CS4313 students and those of the Search Theory and Detection course (OA3602). The general objective of this project is to allow Operations Research (OR) department and CS students, and those of other disciplines, to interact and explore the increasingly important interface between mission-level operations (OR) and technological capabilities and gaps (CS) for autonomous systems.

Students from both classes were teamed to form five separate groups. Using robot simulation and control software, the teams were responsible for jointly (1) informing the planning of the search route of a robot searching for a circular target, such as a land mine, in a cluttered (i.e., obstacle-filled) environment, (2) implementing a search path while avoiding obstacles, and (3) attempting to search as much of the environment in a given time limit.

The CS4313 students implemented robot control algorithms to navigate through the environment and generate data that the OA3602 students would process to determine the average time till the target was first detected.

POC: Dr. Timothy Chung (thchung@nps.edu)

b. Joint Campaign Analysis (JCA) Mini-Briefs (tech injects), WINTER 2011

The NWDC Chair is responsible for this Joint Campaign Analysis (JCA) capstone course which is taught as a seminar in analytical concepts applied to warfare planning and force structure analysis. The course highlight is a class mini-study of a campaign scenario with students using their various curricula knowledge to bound uncertainly, provide insight, and identify risk in concepts and alternative force structures.

The Winter Quarter 2011 class project examined a South China Sea scenario, and assessed the value of an AUWS to both act as an ISR capability and smart underwater weapon system. Similar to the USN distributed network system (DNS), AUWS was determined to add real value to the Blue Force antisubmarine and defense efforts.

POC: Jeff Kline (jekline@nps.edu)

c. Joint JC4I class, SPRING 2011

Students in the NPS course *Policies and Problems in Joint C4I* (CC4913) examined a problematic situation in Nigeria in the Spring Quarter of 2011. The class used a Gulf of Guinea (GoG) scenario titled *A Modular, Mobile C2 Capability*

for the Littorals to generate the C2 requirements and to evaluate the potential solutions for a modular, mobile C2 capability. The mobile C2 capability design was limited by requiring that the mobile system must be deployable and sized to fit on a LCS as well as being capable of being transported by a C-17 aircraft. The class defined the measures of performance for the mobile C2 capability based on maximum throughput (bit rate in megabits per second (Mbps)) and maximum delay time of any data (in seconds).

The Gulf of Guinea Scenario was based on a premise that the Nigerian government requests military assistance from the U.S. to help contain violence in the region and to protect its oil pipelines in a 2018 timeframe. The resulting operation would be controlled locally by a GoG Combined Task Force (CTF) at a Tactical Operations Center (TOC), and that TOC would be supported by the mobile C2 capability named the Network Operations Center (NOC). Other scenario assumptions were conveyed to students. The design of the NOC (*see Figure 5*), its capabilities, and requirements were the focus of the class project.

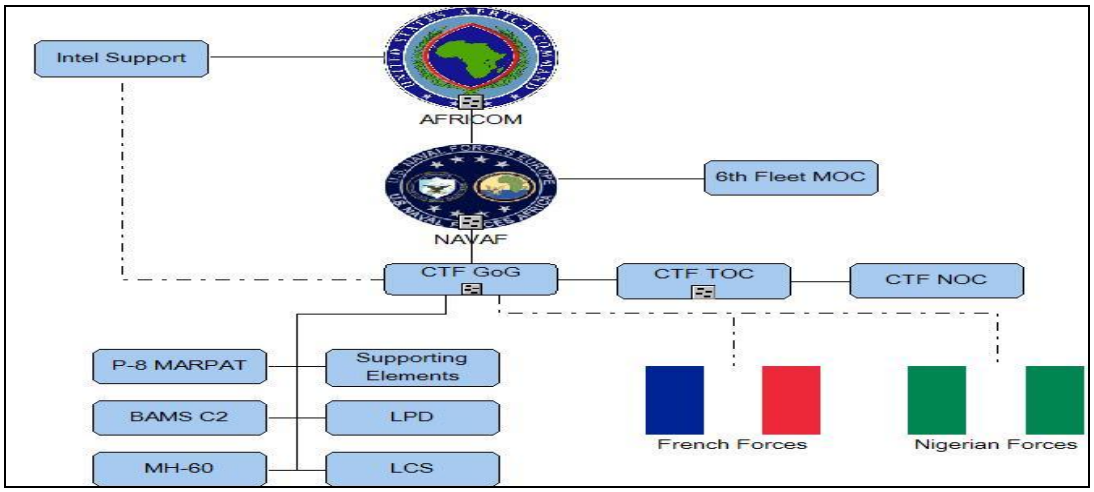


Figure 5. A diagram of NOC assumed relationships for the JC4I class project, Spring 2011

The initial model design was constructed based on the following six assumptions on the applicable technologies available for the 2018 scenario timeframe:

1) The Mobile User Objective System (MUOS) system is available – *currently in development*;

2) there will be only one aerial asset at a time for each surface asset;

3) system interoperability is in place;

4) assets will have both Line of Sight (LOS) and satellite communication (SATCOM) capability; and

5) there will be a continuous flow of data.

The baseline model employed during this class project showed that the NOC would need the capability to receive approximately 8 Mbps via, for example, C-Tel systems. Excursion one of the model showed that the NOC requirement for throughput increased to approximately 15 Mbps. Excursion two of the model showed that the NOC required a throughput of approximately 6 Mbps. Excursion three of the model showed that the NOC required a throughput of approximately 8 Mbps. Variations in the models were accomplished with little effort using the software tool. Use of the altered model designs showed how availability of assets will greatly affect the system throughputs.

The class project to assess the requirements for a mobile C2 capability to facilitate the management of a crisis in the Nigerian region identified several lessons learned. First, an analysis of the technical requirements to support the operation identified the potential for a NOC to be separate from the TOC. The concept is to have a mobile technical capability in the format of a standard shipping container, for example, that would contain the servers, relays, cross domain solutions, etc., and have technical personnel man the TOC to support a feed that would provide information in various formats to a TOC as well as to the 6th Fleet Maritime Operations Center (MOC). By having the technical piece separate from the TOC, the NOC has more mobile capability should the commander of the task force choose to move his TOC from one maritime unit to another or even relocate to a shore station. The TOC can also be scalable to support additional requirements of other networks or to manage scenarios that would require significantly more bandwidth. Additionally, a combined TOC and NOC would not meet the mobility requirements set forth above. A key vulnerability identified in the project was the inability of ship's antennas to focus their SATCOM antennas straight up. In the

GoG area of operations the ships would be operating at or near the equator which would require a ship to point its satellite dishes vertically to reach a satellite at geosynchronous orbit. Design of a mobile C2 center should account for the need to point its satellite dish in any direction. Modeling showed that variations (sometimes, even minor) on the availability of communications assets greatly affect the system throughput for data and should be considered in the CTF's communication requirements when conducting operational planning. Future modeling will enable operational planners to make more accurate assumptions and ultimately prepare leadership to make informed decisions on requirements to support joint or combined operations in similar environments.

POC: Dr. Dan Boger (dboger@nps.edu)

d. Joint Campaign Analysis course, SUMMER 2011

The Summer 2011 Joint Campaign Analysis class project examined UxS employment for military deception and assessed its value in counter-targeting. This was analyzed within the "Two Ocean War 2024" scenario. Analysis results are available upon request.

POC: Jeff Kline (jekline@nps.edu)

e. SEA 17B Capstone Project, SPRING 2011

Sponsored by the CNO Warfare Integration Division Chair of Systems Engineering Analysis, this inter-disciplinary curriculum provides a foundation in systems thinking, technology and operations analysis for warfighters. One of their capstone final topics for FY11 was AUWS which included research on naval UxS. This project was the source of the Winter quarter's Joint Campaign Analysis' AUWS effectiveness assessment (*see report section III:A:2:b*). The SEA 17B AUWS project materials are available for review at: http://www.nps.edu/Academics/Programs/SEA/subpages/projects/2011Spring.html.

B. EDUCATION

CRUSER education programs consist primarily of science, technology, engineering, and math (STEM) outreach events; support for NPS student thesis work; and a variety of education initiatives. These initiatives include sponsored symposia, catalog degree programs, short courses, and certificate programs. CRUSER's education work also involves surveying and aligning curricula for interdisciplinary UxS education.

1. Education Initiatives

With origins in the work of the fledgling Warfare Innovation Continuum, the education initiatives of CRUSER began even before the program was officially begun. In September 2010, the Robotics@NPS Workshop brought together various NPS researchers, educators, and enthusiasts as well as students to learn about ongoing UxS efforts at NPS. From there, events ranged from other campus networking events to guest speakers *(see Table 2*) and development of future symposia.

a. Robots in the Roses, March 2011

Figure 6. Participants interacting at Robots in the Roses, March 2011

Held on 31 March 2011, the first week of Spring Quarter, the Robots in the Roses research fair highlighted all the UxS activity on the NPS campus (*see Figure 6*). This event offered the CRUSER Community of Interest and student community an opportunity to share research and educational opportunities in the areas of unmanned and robotic systems. In remarks delivered during the event, NPS President Oliver commented that, "In addition to capturing all the workshops, war games, projects,

research and experimentation we have done since the beginning of this fiscal year, CRUSER will continue to sponsor, inspire, and participate in concept generation events, at sea testing, technical symposia, classroom projects, education, research, and seminars over the next several years. Regardless of your interest in unmanned systems, from human capital resource requirements to mechanics, CRUSER hopes to capture your work into the community of interest."

b. Continuing Education

In an effort to bring varying perspectives and keep the NPS campus community of interest up to date on current UxS topics and thinking, CRUSER supported the overall campus effort to bring several prominent speakers to Monterey to present on a variety of topics. Table 2 includes a representative listing of these presentations.

Table 2. Representative listing of CRUSER supported presentations on the NPS campus, FY11

MONTH/YEAR	PRESENTER DETAILS
January 2011 –	Dr. Siva Banda, GSEAS Distinguished Lecture series on unmanned aerial systems
	Dr. Malik Ghallab, 4th NPS/MBARI Seminar Series in Robotics and Exploration
February 2011 –	P.W. Singer, Brookings Institution speaking on his new book *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (Penguin, 2009), February 2011
	Menneken Lecture by Mr Jeff Smith, BlueFin
	Physics Colloquium lecture on Acoustic Cloaking by Dr. Jeff Cipolla, Weidlinger Associates
	Dr. Hadas Kress-Gazit presenting as part of the Anthony J Healey Robotics Lecture Series
March 2011 –	Menneken Lecture by Dr. Jim Galambos, Penn State speaking on the LD UUV program
April 2011 –	Menneken Lecture by Dr. Jim Bellingham, Chief Technology Officer of the Monterey Bay Aquarium Research Institute (MBARI)
July 2011 –	Menneken Lecture by Dr. Philip Heermann, Senior Manager, Intelligent Systems, Robotics and Cybernetics (ISRC) Group Sandia National Laboratories presenting "*Unmanned Systems and*

	Robotics, the Next Technology Revolution"
	Dr. Stefano Carpin lecture on "*Bayesian Search with Probabilistic Quadtrees*"
August 2011 –	Dr. Ronald Arkin, Regent's Professor of the School of Interactive Computing and Director of the Mobile Robot Laboratory at Georgia Institute of Technology presenting on "*Governing Ethical Behavior in Lethal Autonomous Systems*."

Future speakers include VADM Joseph W. Dyer, USN (ret.), now the Chief Operating Officer of the iRobot Corporation presenting on "*Robots, Design, and Innovation*" on 3 November 2011; and ADM William Shannon, the UAV PEO from NAVAIR, on 26 January 2012.

Development for the ethics symposium in FY2012, "*Robo-Ethics: Rhetoric vs. Reality*" is well underway. This two-day symposium and education event will be comprised of four, separate two-hour panels focused on cultural, legal and ethical issues affecting policy governing design and use of robotic defense technologies. The event is scheduled for 25-26 January 2012 at the Pentagon, and is open to DoD personnel.

c. UxS Curriculum Alignment

At the direction of the SECNAV, NPS leverages its long-standing experience and expertise in the research and education of robotics and unmanned systems to support the Navy's mission. The establishment of CRUSER serves as a vehicle by which to align currently disparate research efforts and integrate academic courses across discipline boundaries. This ongoing process got underway in earnest in this first start- up year with an initial survey of UxS related coursework across the NPS campus. A preliminary listing of NPS Departments offering UxS courses includes (*see Table 3*):

Table 3. NPS Departments that offered UxS courses, FY11

1) Applied Physics
2) Applied Math
3) Computer Science
4) Electrical and Computer Engineering

5) Information Sciences
6) Mechanical & Aeronautical Engineering
7) Meteorology
8) Modeling, Virtual Environments, and Simulation (MOVES)
9) Oceanography
10) Operations Research
11) Space Systems Academic Group
12) Systems Engineering
13) Undersea Warfare Academic Group

2. NPS Student Theses

Figure 7. Surf zone robot, Halle and Hickle NPS thesis work

To earn an NPS degree, all students must complete a thesis. CRUSER supported several student thesis efforts and other student research in its first program year (*see Table 4*).

Table 4. NPS student thesis work supported by CRUSER in FY11

Thesis project title/subject:	NPS Student (s)
Autonomy in Lethal UAVs	LT Matthew Larkin, USN
Autonomous Surf Zone Robot (see Figure 7)	LT Steve Halle, USN LT Jason Hickle, USN
Multi-Agent Task Negotiation Among UAVs	Mr Michael Day
Search on Optimized Graph Topologies	Major Christian Klaus, German Army
Future of Marine Unmanned Aircraft Systems (UAS) in Support of a Marine Expeditionary Unit (MEU)	Maj Les Payton, USMC
Business Case Analysis of Cargo UAS Capability in Support of Forward Deployed Logistics in OEF	Capt Troy Peterson, USMC LT Jason Staley, USMC
Advanced Undersea Warfare Systems	Systems Engineering Analysis Cross-Campus Study (SEA 17B)

Agent-Based Simulation and Analysis of a Defensive UAV Swarm	Lieutenant Mauricio M. Munoz, Chilean Navy
Derivation of River Bathymetry Using Imagery from Unmanned Aerial Vehicles (UAV)	LT Matthew Pawlenko, USN
Self-propelled semi-submersibles [electronic resource] : the next great threat to regional security and stability	LT Lance J Watkins, USN
The Dispersal Of Taggant Agents With Unmanned Aircraft Systems (UAS) In Support Of Tagging, Tracking, Locating, And Identification (TTLI) Operations	Capt Dino Cooper, USMC
Design Requirements For Weaponizing Man-portable UAS In Support Of Counter-sniper Operations	Maj Derek Snyder, USMC
Autonomous Parafoils: Toward a Moving Target Capability (DISSERTATION)	CDR Chas Hewgley, USN
Family of Unmanned Surface Vehicle Systems Capstone Project	Systems Engineering Analysis Cross-Campus Study (SEA 18B)

NPS theses listed in Table 4 are all on file with the Dudley Knox Library (http://www.nps.edu/Library/), and are searchable on their BOSUN catalog (bosun.nps.edu) under the *Thesis Search* tab. Most NPS theses are also available through the Defense Technical Information Center (DTIC) at www.dtic.mil. The Dudley Knox Library staff compiled a compendium of abstracts for NPS theses related to UxS produced over the last five years. This work is available upon request.

In addition, CRUSER actively solicits and collects potential UxS thesis topics from the on-campus community, as well as Navy labs and other DoD organizations. This list is maintained on the CRUSER wiki for perusal by NPS students still seeking a topic.

3. STEM Outreach Events

"Our overarching STEM objective is simple. Increase, inspire and support the talent pool from which the future's great Sailors, naval scientists and engineers will come."
– ***Chief of Naval Research RADM Nevin Carr***
quoted in Rhumb Lines, 26 April 2011

Figure 8. CRUSER STEM Outreach "Girls Day In" event, March 2011

The USN and USMC team have long been leaders in developing science and technology (S&T) solutions to defend U.S. interests. Currently U.S. is the world's technology leader. However, in recent years the supply of graduates in science, technology, engineering and mathematics (STEM) education has not kept up with an increasing demand. To address this shortfall, the SECNAV set a goal to double STEM investments throughout the next five years to increase hands-on learning opportunities for students and their families; expand opportunities to develop close mentoring relationships; and increase outreach to K-12, underrepresented minority and economically disadvantaged students.

Figure 9. CRUSER STEM Outreach for FIRST Lego League, April 2011

STEM outreach programs rely heavily on naval scientists and engineers serving as volunteers and mentors. These individuals come from a variety of backgrounds, but they all share a commitment to inspiring young people, their schools and communities. STEM outreach activities in this first year of CRUSER included the following on campus and off campus events:

- ***Operations Research Department Robotics Day***, August 2010
- ***FIRST Lego League of Monterey***, November 2010 and April 2011 (*see Figure 9*)
- ***Monterey Academy of Oceanographic Sciences (MAOS)*** visit, March 2011
- ***"Girls Day In,"*** March 2011 (*see Figure 8*)
- ***Robots in the Roses***, March 2011 (*see Figure 10*)
- ***Monterey County Science Fair***, March 2011

Figure 10. CRUSER STEM outreach element of Robots in the Roses, March 2011

C. RESEARCH

At the direction of the SECNAV, NPS leverages its long-standing experience and expertise in the research and education of robotics and unmanned systems to support the Navy's mission. The establishment of CRUSER serves as a vehicle by which to align currently disparate research efforts across the NPS campus as well as among our academic partners and greater community of interest.

Prepared for the DoN UxS CFT, a preliminary sampling of NPS theses and reports on UxS compiled by NPS Dudley Knox library staff members in August 2011 included 152 pages of abstracts from theses, NPS technical reports, journal articles, and conference proceedings. A 25 page annex details the restricted and classified projects.

This compilation of recent NPS reports on UxS is available on the CRUSER wiki at: https://wiki.nps.edu/display/CRUSER/Historical+Completed+Thesis%2C+Project+Work

Since March 2011, CRUSER has attempted to align campus UxS efforts. Faculty researchers have been invited to brief at monthly campus meetings, as well as submit short articles for the monthly CRUSER newsletter. Sponsored research efforts in 2011 were few, with CRUSER in its start-up year. However, in that time CRUSER has already made commitments to support FY12 UxS research efforts both on and off campus.

D. EXPERIMENTATION

CRUSER-affiliated NPS faculty and students engage in their own UxS experimentation, and participate in outside experiments and tests. Aligning parallel efforts and sharing research updates among a greater community of interest will magnify the benefits of all UxS related tests and experimentation.

1. USSOCOM-NPS Field Experimentation Cooperative Capabilities-Based Experimentation - Tactical Network Testbed (CBE/TNT)

Figure 11. NPS students participating in Tactical Network Testbed (TNT) field experimentation

The final U.S. Special Operations Command (USSOCOM) – NPS Field Experimentation Cooperative event of the FY 2011 cycle was conducted from 1-10

November 2011 at the California National Guard's (CANG) Camp Roberts in central California. This event featured three complex experiments in addition to the normal experiments associated with the USSOCOM's mission-based experiments (MBE) and capability-based experiments (CBE). These complex experiments were focused on force protection, over the horizon tactical communications and situational awareness in austere environments. Together with the CBE/MBE force focus areas they yielded a complex mix of technologies and capabilities for exploration by 714 participants representing 90 companies, 80 government organizations and 13 universities. Direct support in both frequency management and technical observation was provided by the National Assessment Group (NAG). In addition to the normal fleet of ground vehicles this event was supported by the National Guard' Task Force Warrior and the Air National Guard with H- 60 and MC-130 aircraft as well as the naval postgraduate schools pelican aircraft. More than 90 sorties were conducted by manned and unmanned aircraft throughout the event.

S&T representatives from each of USSOCOM's component services, as well as two of the Theater Special Operations Commands (TSOCs), were in attendance as well as USSOCOM's S&T Director. Additionally, representatives from U.S. Northern Command (NORTHCOM), U.S. Central Command (CENTCOM) and U.S. Pacific Command (PACOM) participated in the event.

This event featured several novel aspects. For the first time at CBE a UAV was flown with an actual explosive warhead. As often happens in these events, this experiment provided significant learning even though this effort did not lead to successful detonation on the target. NPS, USSOCOM and the CANG all coordinated to enable the safe conduct of this experiment. Similar experiments will easily be supportable in the future due to the lessons learned from this effort.

Also new was the conduct of a complex multi-day scenario experiment conducted by Commander THIRD Fleet/1st Marine Expeditionary Force. This event tied together the resources of not only Camp Roberts but nearby Fort Hunter Liggett in a combat search and rescue (CSAR) scenario that included "actors" playing local adversaries, training for Guard and Air Guard CSAR units, and the evaluation of various tactical radio

systems. This event was unusual for both the duration of the scenario and the realism achieved.

Other trends continued with more than half of the experiments falling in to the command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) areas. Driven by the continued explosion of the civilian personal electronics industry devices continue to improve in performance across the spectrum. Robotic and unmanned systems continue to improve in performance as well. With the exception of small "scout bots" Special Operations Forces (SOF) remain unlikely to use ground robots in large numbers however they have developed a robust capability with air systems. In general, the special operations community should resist the temptation to "lock in" large programs in this area since the rate of innovation remains very high. One potential method to gain some economy of scale while avoiding block obsolescence would be to use both platform specific and agnostic modules, as has been demonstrated at these events, to increase the capability of fielded systems.

Another trend that is probably worth noting is that a fundamental change has already occurred in the nature of end user training for modern technologies. Most soldiers do not use manuals to install and operate their personal electronic devices – in fact they rarely come with the systems. They certainly do not go to multi-week schools to learn how to break gear down for home use. The ability to create devices that can be operated and maintained with little training, and the ability of end users to learn on the fly – with technical support only available via a communications system – along with the ability of systems to, locally or remotely, self-diagnose and sometimes repair themselves; indicates that the opportunity to change the way the military views the training paradigm may be near at hand.

As with most technological innovation a great deal of effort has been aimed at improving existing operational capability but these changes are now reaching the point where novel operational capabilities may be possible. This makes it increasingly important that those responsible for developing new concepts of operations also attend these events to both inspire and be inspired. The USSOCOM J-9 Experimentation team has been regular attendees at these events for this purpose. While it is common for

participants to conduct additional ad hoc experiments, this event marked the first time NPS attempted to collect data on these experiments explicitly. Based on anecdotal observations it has been estimated that ad hoc experiments might run as high as 20% of the total schedule experiment schedule. Included as part of this report are 39 descriptions of ad hoc experiments that were conducted by participants during this TNT 12-1 event.

Finally, a new method of collecting data regarding the potential of each capability examined was used. The data collection model and an example of a summary report for the data collected will be included in the full report on this series of exercises. Both the ad hoc and the potential utility data sets represent attempts to more effectively collect and distribute the knowledge created during these collaborative learning events. These events are generally thought of as providing outstanding value and the emphasis on data collection and the development of metrics will enable the optimizing of these events for the SOF community.

Employing a new Quick Look Report (QLR) format is one attempt to create a more responsive and useful document for the community. The old format will still be created but is now designated the After Action Report (AAR) and will primarily serve as an archive for researchers or those interested in more details about a particular experiment. The AAR will include reports from third parties and the SOF Warfighter Assessments (SWA) as well. The QLR consists of the Director's Hot Wash, a List of Experiments followed by a quad chart for each experiment, the Ad hoc experiment descriptions and a table illustrating the observations of the USSOCOM and its Component Council's representatives with regard to specific experiments.

POC: Dr. Ray Buettner (rrbuettn@nps.edu)

2. Seaweb Maritime In Situ Sensing Inter-Operable Network (MISSION) Project

Persistent maritime surveillance is a challenging problem that requires the deployment of autonomous underwater sensor networks. The Seaweb Maritime In Situ Sensing Inter-Operable Network (MISSION) project will develop and test national through-water acoustic communications and networking capability with emphasis on

operations in noisy environments and cross-nation interoperability. Seaweb MISSION FY11 experimentation in coordination with partners in Singapore is underway, and planning has already begun for continued Singapore Seaweb MISSION experimentation in FY12 (*see Figure 12*).

Figure 12. Site for MISSION 2012 and 2013 sea trials: waiting basin for container ships adjacent to the port of Singapore (*background waters*), and the Singapore Strait (*foreground*), a vital sea lane connecting the Indian and Pacific Oceans.

The NPS Seaweb program and the National University of Singapore (NUS) Acoustics Research Lab have common interests and complimentary skill sets. There exist opportunities to:

- Combine underwater networking technologies developed in the U.S. (Seaweb) and Singapore (UNet) to study and overcome challenges in deploying a maritime surveillance network. Develop interoperable protocols and use the modem's in situ capability to sense the environment and transport information.
- Benefit from numerous existing assets and technologies at NPS and NUS such as modems, sensor nodes, UUVs, etc. Expertise from NPS on deploying large scale networks, and from NUS on communicating and networking in Singapore waters.
- Leverage NPS expertise and technology for underwater wide-area networking that has been demonstrated in diverse maritime environments. The technology relies on telesonar modems to provide low speed long range underwater acoustic communication links.

The Seaweb MISSION project is a bilateral Research Development Test and Evaluation (RDT&E) project that involves collaboration by the U.S. and Singapore in advancing state-of-the-art, through-water acoustic communications and networking technology. Project goals include:

- Study noisy underwater environments.
- Achieve acoustic communications through adverse channels.
- Integrate U.S. Seaweb and Singapore UNet networks.
- Demonstrate in situ environmental and surveillance sensor networks in Singapore Strait.
- Enable distributed wireless architectures for maritime domain awareness (MDA) and undersea warfare (USW).

Singapore presents a challenging environment for underwater communications. NUS has developed underwater modems that have been optimized for performance in Singapore waters. These modems can provide higher speed medium range links to complement the Seaweb modems. The results from the research would not only enable underwater sensor networks to be deployed in Singapore, but also develop technology that could be deployed on demand in other parts of the world. NPS and NUS have numerous assets that have already been developed and can be integrated to enable us to achieve the objectives of this project.

The Seaweb MISSION project will enable researchers to study noisy and variable acoustic communication channels, perform collaborative studies, and conduct long-duration in situ measurements. This project also supports exploration of opportunities for channel-tolerant and channel-adaptive acoustic communications, and enables the project team to conduct controlled signaling experiments (i.e., utilizing Signalex scientific method with parametric analysis of signals and careful measurement of environmental factors) in acoustically challenging and operationally relevant maritime environments (e.g., Port of Singapore, Strait of Singapore, Strait of Malacca).

Other project goals include:

- Advance the Seaweb and UNet state of the art through research and development. Develop underwater networking technology that works well in the challenging waters around Singapore, by drawing upon existing resources and expertise from NPS (Seaweb) and NUS (UNet).
- Broaden the interoperability of U.S. and Singapore through-water communications networks. Establish a working arrangement between NUS and NPS to identify and develop common modalities (e.g., interface standards, acoustic spectrum utilization, modulation protocols, etc.) between U.S. Seaweb and Singapore UNet systems. Deploy an integrated Seaweb-UNet underwater sensor network and evaluate its performance for environmental and surveillance applications.
- Develop a multi-node distributed sensor network concept. Design a surveillance sensor network for operation in swallow-water acoustic environments utilizing fixed and mobile nodes for the detection of surface vessels, self-propelled semi-submersible vessels, submarines, and other maritime threats. Show how such a capability would complement other surveillance capabilities (e.g., AIS, radar) and be integrated with maritime domain awareness infrastructure (e.g., PACOM), national and regional command centers, law enforcement, USCG, USN).
- Test the multi-node harbor defense sensor network concept. Identify available network components (e.g., UUVs, underwater sensors, Seaweb/UNet repeater nodes, Racom gateway nodes, etc.) with relevance to the sensor network concept. Perform Seaweb engineering experiments with these deployable sensor nodes, repeater nodes and gateway nodes. Execute scenario-based demonstrations against controlled targets and targets of opportunity. Record acoustic data containing variable numbers of targets and various ambient noise characteristics.
- Perform post-trials data analysis on the multi-node harbor defense sensor network concept. Collect data, analyze data, and refine the sensor network

concept. Assess operational effectiveness in terms of probability of detection, probability of false alarm, availability, area coverage, latency, endurance, scalability, and other measures of effectiveness.

- Publish results. Prepare and submit test plans, data reports, conference papers, academic research theses, and annual reports. Jointly develop recommendations for operational implementation of the sensor network concept and for future work.

Benefits of this research include:

- Deeper statistical understanding of Singapore's underwater environment that would be critical in deploying operational surveillance systems.
- Development of technologies that may enable persistent surveillance of the maritime underwater environments in Singapore and elsewhere in the world.
- Development of technologies that may allow rapidly deployable short-term underwater sensor networks.
- Development of technologies that may allow the underwater environment to be integrated into operational MDA systems.

Furthermore, this research is highly relevant to our modern world. Threats to the maritime security of both the U.S. and Singapore are broad, including the naval forces of potential adversary nations, terrorism, piracy, and disruption of trade. The attacks on USS Cole in 2000, in Mumbai in 2008, and on MV *Maersk Alabama* in 2009 highlight these very real threats. MDA, that is, identifying threats and providing commanders with sufficient awareness to make timely decisions, is a means for facilitating effective action in the maritime domain and is critical to homeland defense. Relevant MDA and USW missions enabled by MISSION technology include ISR, meteorology and oceanography (METOC), anti-submarine warfare (ASW), Naval Special Warfare (NSW), mine warfare (MIW), and mine countermeasures (MCM).

Figure 13. Seaweb MISSION project engineering experimentation site, Del Monte Lake on the NPS campus in Monterey

The sponsored portions of the U.S. contributions are derived in approximately equal measure from two sources, CRUSER and ONR. In keeping with the CRUSER charter, the CRUSER funds will tend to be directed toward research on the NPS campus, including procurement of equipment, operation of facilities, and work performed by NPS faculty and students. Specific CRUSER expenditures include acquisition of Seaweb modems and hardware, establishment of on-campus Seaweb laboratories, preparation and operation of an on-campus test site at Del Monte Lake (*see Figure 13*), engineering testing on the bench, project-relevant labor and travel for the Principal Investigator, funding for student research, and expenses associated with conference presentations and publications. The ONR funds will be issued to NPS and will largely cover the contributions by U.S. subcontractors Teledyne Benthos, Inc., SPAWAR Systems Center Pacific, and University of Texas Applied Research Labs. This division of investment will realize the maximum potential technological yield per invested dollar. In the case of the ONR funds, NPS has established contractual mechanisms for disbursing funds to the identified subcontractors without any pass-through overhead costs. In the case of the CRUSER funds, the prescribed funding of on-campus activities will foster participation and contributions in kind by other faculty and students using non-MISSION funds from CRUSER and other leveraged programs. A case in point is the FY11 procurement of a WaveGlider USV using a combination of NPS recapitalization funding and corporate

sponsorship by Liquid Robotics. The WaveGlider USV will be developed as an unmoored station-keeping gateway node for Seaweb networks.

This is a multiyear project, starting with initial planning in FY11. FY12 will start year one with anticipated completion at the start of FY14 with final sea trials in October 2013 and results published in December 2013. A more detailed timeline is available.

POC: Professor Joe Rice (jarice@nps.edu)

3. Maritime Interdiction Operation (MIO) Demo, July 2011

In July 2011, CRUSER sponsored researcher Dr. Alex Bordetsky conducted a maritime interdiction operation (MIO) remote sensor control demonstration in Singapore. In real time, Dr. Bordetsky controlled an unmanned surface vehicle's (USV's) sensor package operating in Europe in front of a Singapore audience. The worldwide coordination capability was done as a test of collaborative software.

POC: Dr. Alex Bordetsky (abordets@nps.edu)

4. Research and Experimentation for Local & International Emergency and First Responders (RELIEF)

Research and Experimentation for Local and International Emergency and First Responders (RELIEF) is a quarterly field experimentation cooperative held at Camp Roberts National Guard base in Paso Robles, California. The event brings together disaster relief technologies for a week of field testing and collaborative work.

The Spring 2011 RELIEF experiment was conducted during MBE week, 3-6 May 2011; and were focused on triaging incoming social media messages and crowd sourced material to create real time situational awareness and deployable communications hubs, testing internet protocol communications networks, and tools for disarming chemical, biological, radiologic and nuclear (CBRN) devices. NPS CRUSER faculty and staff were encouraged to attend as it involved use of UxS.

One element of this experiment used the Camp Roberts Emergency Operations Center (EOC) as the focus for coordinating the receipt, processing, dispatch and reporting of hundreds of text messages containing field reports that included position and status for

refugees following a simulated disaster. This experiment used social media tools to both collect and process these messages. The international volunteer technical community, to include participants from more than a dozen foreign nations, participated in the processing of these messages in near real time demonstrating the potential for a significantly faster response to disasters using these systems.

5. EcoMapper UUV

As future Navy SEALs swim silently toward shore, they will be armed with validated 3D maps of the tides, waves and currents between their location and the target thanks to cutting-edge research by a Naval Postgraduate School faculty-student team. NPS Assistant Professor of Oceanography Jamie MacMahan led the seven students in his Littoral Field Studies course in a 10-day capstone field experiment collecting tidal inlet measurements using man-portable UUVs and feeding the data into the Navy's nearshore Delft3D model. Two years ago, Dr. MacMahan developed a course focusing on nearshore and surfzone projects aligning with the USN focus on littoral environments, which are more complex and challenging than the deep ocean due to faster flows and more rapid changes. Spatially mapping the velocity field is critical for many expeditionary warfare exercises, particularly those involving human swimmers such as Navy SEALs. Professor MacMahan then added an operationally relevant, hands-on exercise in a fast-flow, tidally dominant estuarine environment to his NPS course in collaboration with partners at the University of Miami and NUWC.

Applying a two-dimensional (2D) divergence-free interpolation (DF) to the one-person deployable UUV's noisy Moving-Vessel Acoustic Doppler Current Profiler (MV-ADCP) measurements improves the results and increases the utility of the UUV in tidal environments. For a 3.5-hour MV-ACDP simulation that spatially and temporally varies with the M2 tide, the 2D DF-estimated velocity magnitude and orientation improves by approximately 85%. Next the 2D DF method was applied to velocity data obtained from two UUVs that repeatedly performed seven 1-hr survey tracks in Bear Cut Inlet, Miami, FL. The DF method provides a more realistic and consistent representation of the ADCP measured flow field, improving magnitude and orientation estimates by approximately

25%. The improvement increases for lower flow velocities, when the ADCP measurements have low signal-to-noise ratio. However near slack tide when flow reversal occurs, the DF estimates are invalid, because the flows are not steady state within the survey circuit.

Figure 14. NPS Professor Jamie McMahan and students with EcoMapper UUV

"Tidal inlets are important to the Navy's littoral focus, because when you move from the deep ocean to any land water body, you have to go through an inlet," stated MacMahan. The research question posed to the student project team was 'If you only have UUVs, how do you get the best observational data using specialized research and numerical models that many of the students will utilize in the future?' This addition is a unique exploration and educational opportunity for Professor MacMahan's students that simultaneously tests transformative ideas that can be integrated into future naval operations. "The experimental scenario is of direct operational value to the Navy because special operations and expeditionary warfare use these same tools [UUVs and Delft3D], and this is the first time smaller UUVs have been used in fast-flow inlet or riverine environments. The concept for the capstone project evolved from initial discussions between Dr. MacMahan and doctoral student LCDR Bill Swick, one of the two teaching assistants for the course, who has experience with both special and expeditionary operations.

This course project allowed students to learn how to program and deploy the NPS EcoMapper UUV to collect real-time data on waves, currents, temperature, salinity, sediments, pollutants and bathymetry amongst other measures. They also learned first-hand how to input the data into the numerical model, and how to output the resulting

maps using Google Earth and Matlab. "And while they're doing this, they get to explore a real, complex shallow-water environment – the highly energetic Bear Cut tidal inlet near Miami, Florida," MacMahan noted. The students got the model up and running in about a day and were able to run three missions in strong, two meters-per-second currents.

Figure 15. NPS students launching EcoMapper UUV during field experimentation

MacMahan's tidal inlet class exercise was sponsored by N4/N7 Assistant Chief of Staff for Readiness, Training and Education, Mr. Rich Jeffries, and funded by Dr. Tom Drake of the Office of Naval Research Coastal GeoSciences program.

POC: Dr. Jamie MacMahan (jhmacmah@nps.edu)

6. Center for Autonomous Vehicle Research (CAVR)

Research Assistant Professor Douglas Horner and Professor Isaac Kaminer with the NPS Graduate School of Engineering and Applied Sciences (GSEAS), Department of Mechanical and Aerospace Engineering, are the co-directors of the CRUSER-affiliated NPS Center for Autonomous Vehicle Research (CAVR). The primary goal of CAVR is to educate USN and USMC officer students in the development and use of technologies needed for unmanned systems through coursework, thesis and dissertation research.

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Figure 16. NPS CAVR UUV showcase 2011:
Professors Tony Healey (second from left) and Doug Horner (left) co-principal investigators for CAVR with students and UxS.

The secondary goal of the Center is to advance Naval UxS operations by providing:

- Support to the Fleet, Navy Labs and Program Offices
- Testing and Experimentation of Advanced Technologies
- Independent Verification and Validation of UUV Concepts, and
- Innovative Concept Development

Research is conducted into topics falling in the following broad areas: underwater navigation, control and communication; tactical decision aids (TDAs); collaborative multi-vehicle operations; obstacle avoidance (OA) using forward look sonar; and common UUV mission description language.

POC: Research Assistant Professor Douglas Horner (dphorner@nps.edu)

7. Trident Warrior 2011

The overall objective of the Distributed Information Systems Experimentation (DISE) program is to plan and execute large-scale experimentation of new technologies and tactics to support the joint warfighter.

DISE group CRUSER related experimentation this fiscal year included work with Trident Warrior 2011, held in July 2011. Multiple technologies were assessed for potential use and integration into their present mission. A Military Utility Assessment

(MUA) was developed using empirical findings demonstrating ramifications of proposed new technologies and policy changes. Improved efficiencies and SA were determined

Future efforts include plans to provide analysis for EC10, combining multiple technologies – both real and synthetic; and to demonstrate the usefulness of the Joint Multi-Mission Electro-Optical System (JMMES) using simulation.

POC: Dr. Shelly Gallup (spgallup@nps.edu) and Dr. Doug MacKinnon (djmackin@nps.edu)

8. Black Dart 2011

Black Dart is an annual demonstration that uses DoD, interagency, industry, and academia/laboratory Programs of Record (PORs) and near-term capabilities and technologies to support the warfighter's emerging counter-UAS requirements. Black Dart is designed to test the military's capability to detect and counter enemy UAS systems, and to see what technology industry has to offer and test it against potential threat UxS. Black Dart 2011 was focused on demonstrating counter-UAS tactics in the littoral/maritime environment. Rather than focusing on specific systems, the goal of the annual Black Dart exercise is to see how broad technology and doctrine capabilities work.

Black Dart 2011 took place at Naval Base Ventura County (NBVC) at Point Magu, California in August 2011. The large size of the operational area also allowed nearly limitless operating space. The exercise involved 47 UAVs flying 120 sorties. A USN destroyer conducted live fire tests and shot down a variety of UAS platforms. One of the goals of the exercise is to determine what works and what does not in terms of detecting and countering UAS platforms.

CRUSER sponsored NPS student and faculty participation in Black Dart 2011. Planning efforts are now underway for Black Dart 2012, the second iteration of this counter-UAS demonstration in the littoral/maritime environment at NBVC.

E. OUTREACH

In this first CRUSER program year, outreach has been a priority. The CRUSER leadership team has made huge strides in socializing the concept and mission thread of the program through individual briefings, conference attendance by leadership or representatives of the program, and targeted invitations in the monthly CRUSER newsletter. At the end of each personally delivered brief guest are offered the opportunity to join the ever-growing CRUSER community of interest. Not only has the CRUSER community of interest grown to nearly four hundred in seven months, but also so many CRUSER briefings for visitors to the NPS campus have been requested that the program has re-designed its coordination office to serve as a venue for such briefings.

1. Community of Interest

Another basic CRUSER goal is to develop an UxS community of interest (CoI). Begun in advance of the official program launch, the CoI grew quickly over the first several months (*see Figure 17, right*). As of the end of FY11 (30 September 2011) the CRUSER CoI included over 370 members split between several representative categories (*see Figure 17, left*). In this first program year, several initial efforts have been targeted to reach this goal. First, a monthly CRUSER newsletter is sent to an ever-growing distribution list. This monthly newsletter is designed to facilitate the sharing of current activities, ongoing projects, common research questions, and other relevant topics among the CRUSER Community of Interest. Each issue also includes a "Student Research: In-Progress" feature to showcase ongoing student UxS work, at NPS and at other academic institutions.

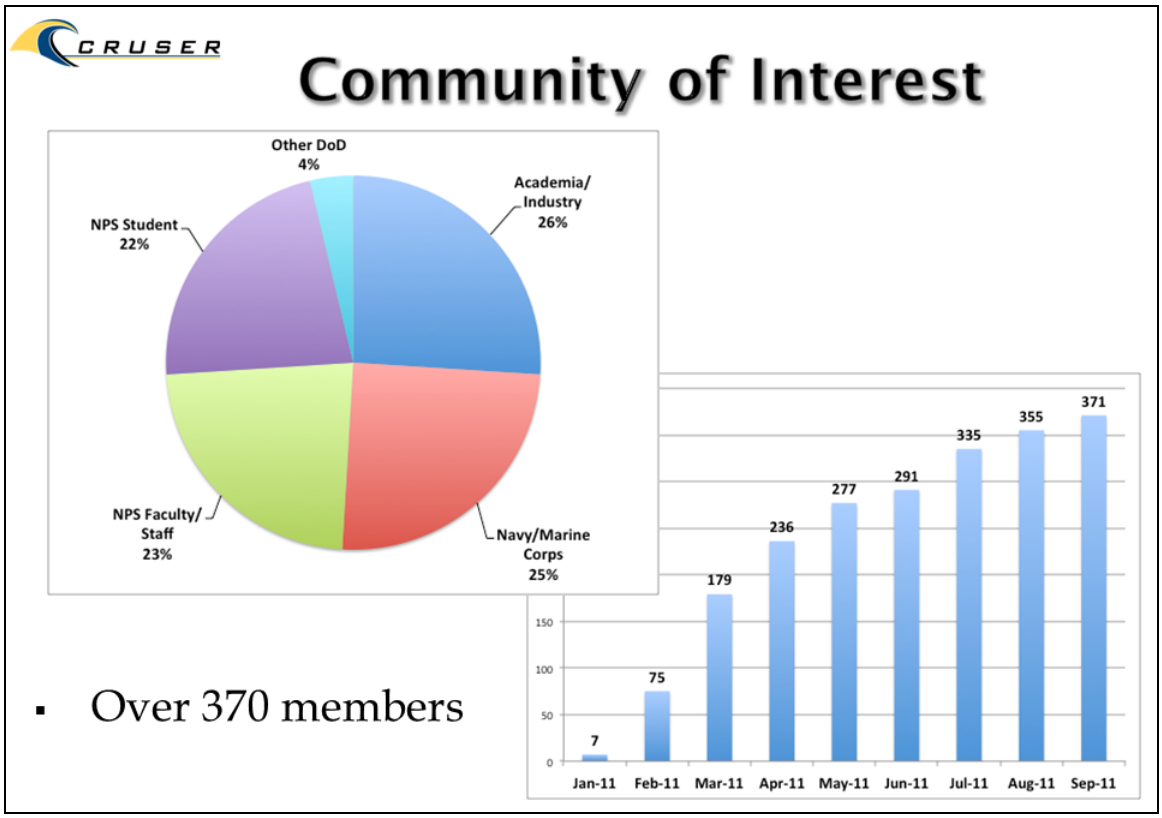

Figure 17. CRUSER community of interest as of September 2011

Monthly campus meetings provide a forum for NPS students and researchers to brief the NPS CRUSER community on their project work (*see Figure 18*), and share trip reports from UxS conferences and symposia worldwide. CRUSER leadership uses the monthly meetings to announce upcoming events, solicit input on future plans, and request proposals. Observation in other settings supports the "conference table" or "round robin" platform in scientific innovation. Researchers benefit from sharing thoughts and getting feedback.

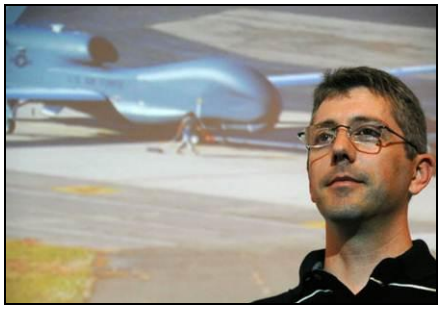

Figure 18. Maj James Lotspeich, USAF presenting at CRUSER monthly meeting (July 2011)

Finally, the CRUSER Operations Manager also maintains a CRUSER wiki page at https://wiki.nps.edu/display/CRUSER/Welcome+to+CRUSER where members are able to view the latest calendar announcements, education and research updates, as well as UxS related news and other resources mined from a variety of sources. The CRUSER Operations Manager also maintains a general public website for the program at cruser.nps.edu and a classified website at https://cruser.nps.navy.smil.mil.

The current solicitation phrase for the CRUSER community of interest is included in each issue of the newsletter, and reads:

> **Join the CRUSER community of interest!** Visit us at http://CRUSER.nps.edu
>
> - Receive CRUSER e-newsletters with updates on unmanned research
> - Be invited to symposia related to your area of interest
> - Participate in Unmanned Systems experimentation
> - Aid in development of Concept Generation

Faculty and students across nearly a dozen disciplines at NPS comprise an active robotics and UxS research and education program. Numerous robotics and UxS research and experimentation efforts exist throughout the Navy enterprise, including a growing collection of collaborating and associated institutions. Additionally, CRUSER membership includes other DoD organizations, research institutions, and private sector companies. Appendix D provides a representative listing of current CRUSER membership (*see p. 65*).

2. Briefings

In this first year of the program, CRUSER leadership gave briefings almost weekly. Appendix B provides a representative sample of the briefings delivered (*see p. 61*). These briefings were important outreach and community of interest building events. Briefings included CRUSER's goals, mission, sponsorship, and current activities, and future plans.

In order to facilitate campus briefings, CRUSER set up a coordination office on campus in Bullard Hall (*see Figure 19*).

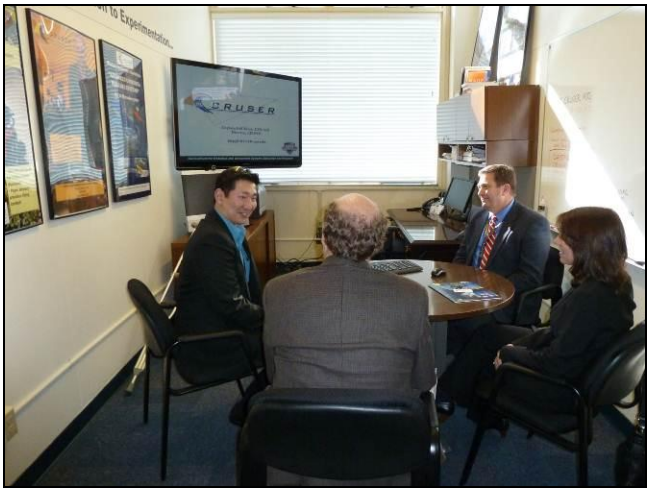

Figure 19. CRUSER Coordination Center (CCC), Bullard Hall room 118

3. Conferences

In this first year of the program, CRUSER sponsored several NPS students and faculty members to attend mission related conferences (*see Table 5*).

Table 5. CRUSER-sponsored conference attendees (*listed chronologically*)

DATE (mo/yr)	**ATTENDEE(s)**	**EVENT**
January 2011	LT M. Larkin	***ISME 2011*** *– International Conference on Ethics in Emerging Military Technologies (San Diego CA)*
	Dr. T. Chung	***ONR UxS Technology Review*** *(Panama City FL)*
April 2011	Dr. R. Buettner	***AFCEA West*** *Conference*
	Dr. T. Chung	***ONR Science of Autonomy Program Review*** *(Arlington VA)*
	M. Dankel	***2011 McCain Conference*** *(U.S. Naval Academy, Annapolis MD)*
	S. Kragelund	***USV Community of Interest Users Workshop***
May 2011	Dr. T. Chung	***ICRA*** *– Robotics and Automation Conference*
	W. Hatch	***NDU Conference***
June 2011	K. Gonzales	***Naval STEM Forum***
	Maj J. Lotspeich and P. Ateshian	***Beale AFB*** *tour and briefings*
July 2011	LTJG L. Murphy and LT F. Megna	***Trident Warrior 2011***
September 2011	C. Hewgley and R. Severinghaus	***IROS 2011*** *– International Conference on Intelligent Robots and Systems (San Francisco CA)*

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III. CONCLUSION

FY11 was CRUSER's startup year. The program has developed a lean coordinating organization; started a monthly CRUSER newsletter, website, and wiki; held monthly campus meetings to build a resident CoI; conducted concept generation events; grown to over 400 members; and provided student opportunities in research and experimentation. CRUSER has also developed a plan for the future.

The overarching CRUSER mission thread (*see Figure 20*) gives a broad overview of programming themes through FY13, centering around the UxS concept generation begun in September 2011 with the CRUSER WIW 2011, through field experimentation in early FY13, and ending with a UxS tech exposition event in Washington DC.

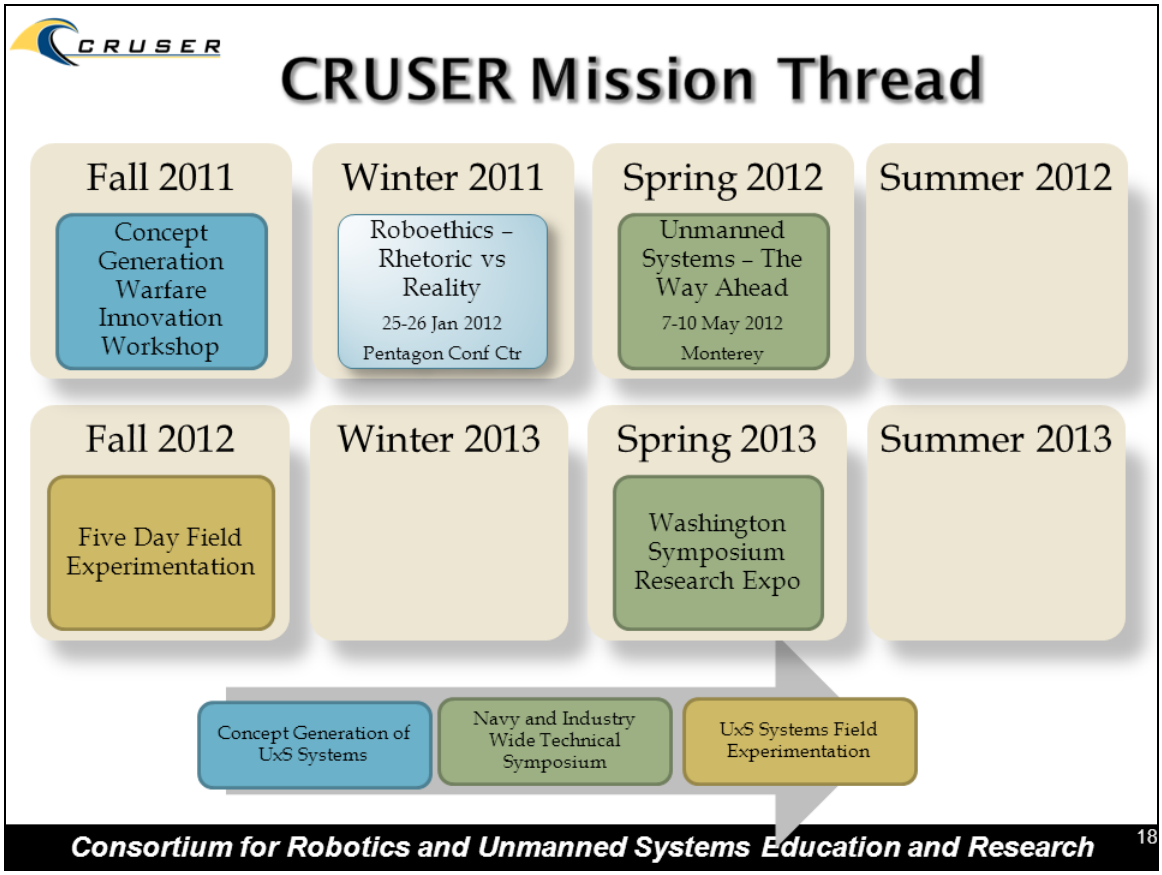


Figure 20. CRUSER mission thread overview, September 2011

A. PROPOSED FY12 ACTIVITIES

In FY12, CRUSER will continue to sponsor workshops, coursework, and symposia. Planning for several of these events is already underway. As mandated, CRUSER will also support UxS research and experimentation.

1. Workshops, Coursework, and Symposia

The NWDC chair is responsible for developing and delivering WIWs that focus on innovative Concept Generation and Concept Development in maritime operations. The Chair will continue to coordinate closely with NWDC leadership and the SECNAV-sponsored CRUSER to facilitate several workshops and advance innovation education among NPS students. Proposed events for FY 2012 include:

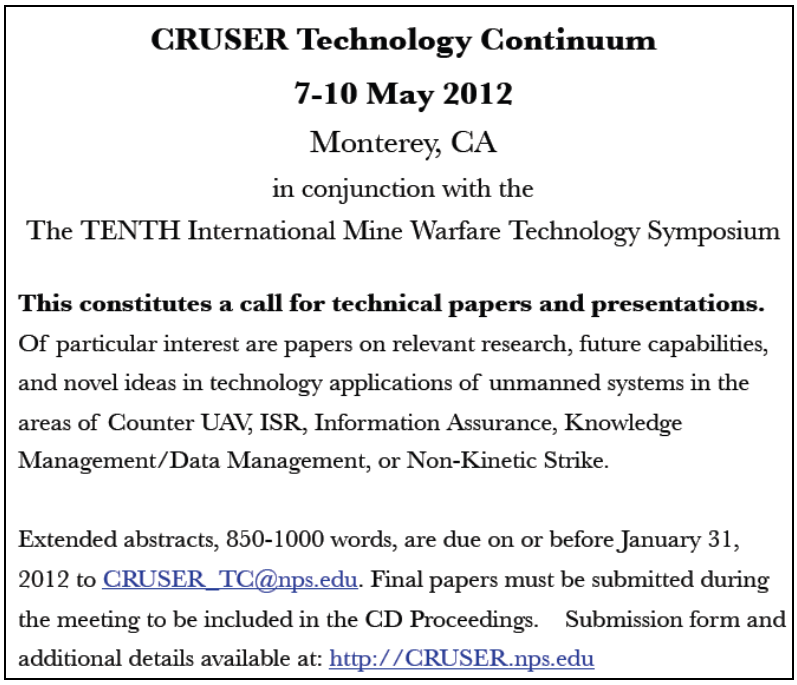
a. Roboethics: Rhetoric vs. Reality

On Wednesday and Thursday, 25-26 January 2012, ONR, N2/N6 and CRUSER will sponsor a two-day symposium comprised of four, separate two-hour panels focused on cultural, legal and ethical issues affecting policy governing design and use of robotic defense technologies. The goal of this symposium for the warfighter is to differentiate between rhetoric and reality with regard to risks, opportunities and obligations involving unmanned, remotely operated, and fully autonomous robotic systems, platforms and weapons. Each panel is designed as a stand-alone presentation so Pentagon uniformed and civilian personnel may attend those panels that are the best fit with their professional interests and responsibilities. To leverage both operational and academic experience, ensure credibility, and minimize costs, panelists are primarily drawn from the USN's three degree-granting institutions: the Naval War College, NPS, and the U.S. Naval Academy.

b. UxS Technology Continuum

Scheduled for 7-10 May 2012 in Monterey, this event is designed to be a follow-on to the CRUSER WIW 2011; and will be held in conjunction with 10th International Mine Warfare Technology Symposium "*Mines, Counter Mine, and*

Unmanned Systems – The New Horizon." The combined event sponsored by NPS, ONR, the Program Executive Office/Littoral Combat Ships (PEO/LCS), OPNAV (N85), and CRUSER is being announced as the TENTH International Mine Warfare Technology Symposium. A call for technical papers and presentations was released in the ninth issue of CRUSER News at the beginning of November 2011 (*see Figure 21*), and submissions are due by the end of January 2012.



CRUSER Technology Continuum

7-10 May 2012

Monterey, CA

in conjunction with the

The TENTH International Mine Warfare Technology Symposium

This constitutes a call for technical papers and presentations. Of particular interest are papers on relevant research, future capabilities, and novel ideas in technology applications of unmanned systems in the areas of Counter UAV, ISR, Information Assurance, Knowledge Management/Data Management, or Non-Kinetic Strike.

Extended abstracts, 850-1000 words, are due on or before January 31, 2012 to CRUSER_TC@nps.edu. Final papers must be submitted during the meeting to be included in the CD Proceedings. Submission form and additional details available at: http://CRUSER.nps.edu

Figure 21. CRUSER Technology Continuum call for papers, November 2011

The event is unclassified with foreign participation expected and welcome. Naval and industry plenary speakers will address a broad range of topics including the current status and future requirements of mine warfare technology. Break-out sessions will showcase basic scientific and emerging technology research with applications to the undersea environment and specialized sessions focused on LCS centric mine warfare, advanced undersea warfare systems, mine warfare applications in maritime homeland defense, gliders, environmental research and developments, operational data flow and communications, and other related topics. Many of the topics covered above will likely exploit unmanned systems to aid in meeting particular technical requirements.

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c. Joint Campaign Analysis Class

As in past quarters, this capstone course will continue to be delivered as an applied seminar in analytical concepts applied to warfare planning and force structure analysis. The highlight of the course is a class mini-study of a campaign scenario with students using their various curricula knowledge to bound uncertainly, provide insight, and identify risk in concepts and alternative force structures. Within these scenarios students are asked to develop concept of operations and quantitatively evaluate them for risk of mission accomplishment. In addition, they are given new technical injects for evaluation. As in the past, the best papers from this class are provided to NWDC, OPNAV, and fleet staffs. NWDC and the CRUSER community also have the opportunity to shape the scenarios and technical injects into this class.

d. Systems Engineering Analysis (SEA) Curriculum and Capstone Project

Sponsored by the Warfare Integration Division CNO Chair of Systems Engineering Analysis, this inter-disciplinary curriculum provides a foundation in systems thinking, technology and operations analysis for warfighters. Their capstone topic for this year will involve a large review of amphibious requirements and the future landing ship dock – future (LSD-X) and applications for USVs. The Chair will support this project through thesis support and student travel. NWDC representatives will be invited to hear the final briefings for this cross-campus integrated study.

2. Research and Warfare Analysis

In March 2011, CRUSER made its first call for proposals to seed research topics. The stated funding period was 31 October 2011 through September 2012, and the funding levels were set at $75,000 to $125,000. Researchers were asked to submit proposals in one of the following five general subject areas:

1) Technical

2) Concept Generation

3) Experimentation

4) Human Capital Requirements

5) Social, Cultural, Political, Ethical and Legal

Proposals were due at the beginning of August 2011. Nineteen proposals, totaling more than $1.9m in requests were submitted. The CRUSER on-campus advisory board selected six projects to receive a total of $400k to being work in FY12 (*see Table 6*).

Table 6. FY12 CRUSER funded research projects

PRINCIPAL INVESTIGATOR	PROJECT TITLE
Dr. Roberto Cristi & Dr. Oleg Yakimenko	Passive UxV Navigation using Visual Sensors
Dr. Patrick Harr	Tropical Cyclone Reconnaissance with the Global Hawk: Operational Requirements, Benefits, and Feasibility
Dr. Peter Chu	Joint Optimization of Sensing and Sampling with Unmanned Undersea Vehicles
Dr. Dan Nussbaum	Roadmap for Reduction of Total Ownership Cost (TOC) to Support Acquisition Decisions of Unmanned Autonomous Vehicle - Phase I
Dr. George Lucas & Mr. Mark Dankel	Programming the Laws of Armed Conflict (LOAC) for Unmanned Systems
Dr. Noel du Toit & Professor Doug Horner	Autonomous Multi-vehicle Tactical Surveillance and Support for Maritime Visit, Board, Search and Seizure Operations - Part II

a. Project Jason, Counter UAV Analysis

This research, both unclassified and classified, has identified threat characteristics and potential counter measures to defeat enemy UAVs. Research conducted in response to Chinese open-source literature regarding potential future warfighting tactics and procedures. Scenarios studied to date are single ship versus UAV

swarm; single ship vs. multi-missile and multi-axis attack; and multi-ship response. The current project is evaluating swarm versus swarm response in coordination with the NPS Operations Research Department and Systems Engineering Department.

b. Maritime Operational Planning aids

This is a major research effort by NPS Operations Research faculty to apply state-of-the-art optimization techniques to build planning aids for operational level staffs such as the MOC. Many of the aids integrate UxS employment.

c. Analytical support to field experimentation programs

This effort will continue to provide funding for thesis students to participate in the NPS field experimentation programs which focus on tactics, techniques and procedures to employ and control unmanned vehicles and networks field experimentation programs.

B. LONG TERM PLANS

Projected to continue into FY13, CRUSER plans to catalog degree programs, short courses, and certificate programs nationwide. Other long term plans include the creation of short course programs as identified by community of interest, and a continued effort to align curricula for interdisciplinary autonomous systems education on the NPS campus.

Begun with the CRUSER WIW 2011 in FY11, and then continued in FY12 with the UxS Technology Continuum, FY13 will close the first full cycle of concept generation to experimentation with the CRUSER Research Expo in Washington DC. Specific activities include:

1. UxS Experimentation

By early 2013 the concepts developed for the UxS Technology Continuum, generated in the CRUSER WIW 2011, will be demonstrated and refined in five days of field experimentation at Camp Roberts in Paso Robles, California.

2. UxS Research Expo

The fully developed and demonstrated concepts that were initially generated during the CRUSER WIW 2011 will be introduced to the federal level community of interest at the Washington DC Symposium Research Expo in Spring 2013.

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APPENDIX A: SELECTED PUBLICATIONS AND TECHNICAL REPORTS

Brutzman, D., with T. Chung, C. O'Neal, J. Ellis and L. Englehorn (2011). *Future Unmanned Naval Systems (FUNS) Wargame Competition Final Report* (NPS-USW-2011-001) released July 2011.

Kline J. and L. Englehorn (2011). *Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) Warfare Innovation Workshop (WIW) 2011 After Action Report*, released October 2011.

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APPENDIX B: SELECTED PRESENTATIONS

This list of briefings is representative of those given by CRUSER leadership in the first program year. It is not meant to be inclusive, only give a sense of the depth and breadth of interest in CRUSER.

DATE (mo/yr)	**AUDIENCE (affiliation: name/s)**
January 2011	***Naval System Technology:*** *CAPT James Durham, USN (ret.)*
	Department of State: *Ambassador Mary Yates*
	JHU/APL: *Mr. Jack Keane and Mr. Glen Mitzel*
	PACOM: *Science Advisor*
	N2/N6: *Mr. Brett Vaughn*
February 2011	***Bluefin Robotics:*** *Mr. Jeff Smith*
March 2011	***OPNAV N-81B****: Mr. Trip Barber, CDR Robert Bruce, and Mr. Herb Cupo*
	OPNAV N52 *(International Engagement): LCDR Manny Hernandez*
	Deputy Under SECNAV for PP&I*: Mr. Mark Gorenflo*
	OPNAV N2/N6F*: Mr. Paul Siegrist, Unmanned Systems and Sensors*
	Penn State/LDUUV Program: *Dr. Jim Galambos*
	PPCO President Naval War College: *RADM John Christenson*
	ONR Global: *Dr. Clay Stewart*
	PCO COMTHIRDFLT: *RADM Gerald Beaman*
April 2011	***PCO President INSURV:*** *RADM Robert O. Wray*
	E-Ring Consulting: *Gerry Roncolato*
	PCO CNMPC: *RADM Cynthia Covell*
	PCO COMNAVSPECWARCOM: *RADM Sean Pybus*
	SSC Pacific: *Mr. Steve Koepenick*

May 2011	***Under SECDEF International Cooperation:*** *Mr. Alfred G. Volker*
	SUBRON THREE: *CAPT Daryl Caudle*
	OPNAV N2/N6F: *RDML Matt Klunder*
	N81: *RADM Arthur Johnson*
	USFF N3/5/7: *RADM Patrick Driscoll*
	Moldova Armed Forces: *Alexandru cel Bun Military Academy delegation*
June 2011	***SPAWAR San Diego:*** *J.D. Morrison*
	Northrop Grumman: *Mr. Arun R. Palusamy and Mr. Michael Budney*
July 2011	***ESG 5 Bahrain from N86F:*** *RDML Fanta*
	MINDEF Singapore: *QUEK Tong Boon, Dr. Cheng, Wei Ping, NG Seng Loeong*
	Naval Research Lab
	Sandia National Laboratory
August 2011	***DoN UxS CFT****: Mr. Ed Hackett, Mr. Jim Shannon, and CAPT Zwick*
	JCS J2: *Mr. Lee Allen and Mr. Marcus Williams*
	FLTCYBERCOM/C10F: *Dr. Starnes Walker*
	Commodore Merz
	MITRE
September 2011	***PMS 404:*** *CAPT Tom Kearney*
	PD/DUSN: *Mark Gorenflo*
	Carnegie Mellon Software Engineering Institute: *Terry Roberts*

APPENDIX C: SELECTED THESES AND PROJECTS SUPPORTED

This list is repeated from the text of the document (*see pp. 26-27*). Unclassified NPS theses are available through the NPS Dudley Knox Library and DTIC.

Thesis project title/subject:	**NPS Student (s)**
Autonomy in Lethal UAVs	LT Matthew Larkin, USN
Autonomous Surf Zone Robot (see Figure 7)	LT Steve Halle, USN LT Jason Hickle, USN
Multi-Agent Task Negotiation Among UAVs	Mr Michael Day
Search on Optimized Graph Topologies	Major Christian Klaus, German Army
Future of Marine Unmanned Aircraft Systems (UAS) in Support of a Marine Expeditionary Unit (MEU)	Maj Les Payton, USMC
Business Case Analysis of Cargo UAS Capability in Support of Forward Deployed Logistics in OEF	Capt Troy Peterson, USMC LT Jason Staley, USMC
Advanced Undersea Warfare Systems	Systems Engineering Analysis Cross-Campus Study (SEA 17B)
Agent-Based Simulation and Analysis of a Defensive UAV Swarm	Lieutenant Mauricio M. Munoz, Chilean Navy
Derivation of River Bathymetry Using Imagery from Unmanned Aerial Vehicles (UAV)	LT Matthew Pawlenko, USN
Self-propelled semi-submersibles [electronic resource] : the next great threat to regional security and stability	LT Lance J Watkins, USN
The Dispersal Of Taggant Agents With Unmanned Aircraft Systems (UAS) In Support Of Tagging, Tracking, Locating, And Identification (TTLI) Operations	Capt Dino Cooper, USMC
Design Requirements For Weaponizing Man-portable UAS In Support Of Counter-sniper Operations	Maj Derek Snyder, USMC
Autonomous Parafoils: Toward a Moving Target Capability (DISSERTATION)	CDR Chas Hewgley, USN
Family of Unmanned Surface Vehicle Systems Capstone Project	Systems Engineering Analysis Cross-Campus Study (SEA 18B)

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APPENDIX D: PARTNERSHIPS

This is a representative listing of the CRUSER community of interest in the first program year. It is not meant to be inclusive, but is included to demonstrate depth and breadth of interest.

USN and USMC Organizations:	Joint Unmanned Aerial Systems, Center of Excellence
	Marine Corps Combat Development Command, Operations Analysis Division
	NAVAIR
	Naval Special Warfare
	Naval Surface Warfare Command, Carderock
	Naval War College
	Naval Undersea Warfare Command, Newport
	SSC-Pacific
	Unmanned Anti-Submarine Warfare Support Facility, Narragansett Range *(expected February 2012)*
DoD Institutes:	Joint Unmanned Aerial Systems - Center of Excellence (Nellis AFB, NV)
	U.S. Army Robotics Center of Excellence (Fort Hood, TX)
	U.S. Army Unmanned Aerial Systems - Center of Excellence (Fort Rucker, AL)
Other DoD Organizations:	DoD – TACOM
	Joint Ground Robotics Enterprise
	OSD ATL
	PEO GCS - RS JPO
	Robotic Systems Joint Project Office

(Other DoD Organizations *continued***)**	TACOM
	USMA - Engineering Psychology
	U.S. Army - RS JPO
Non DoD Organizations:	Autonomous Undersea Vehicle Applications Center (AUVAC)
	Georgia Tech Research Institute
	Johns Hopkins Applied Research Laboratory
Academia and Industry:	AAI Corporation
	Alpha Research & Technology, Inc.
	Arizona State University
	Booz Allen Hamilton at Navy Warfare Development Command
	California State University, Monterey Bay
	Charles River Analytics
	Compsim LLC
	CS Draper Laboratory
	Department of Aerospace and Mechanical Engineering, University of Notre Dame
	Dynetics
	Executive Leadership Group
	General Dynamics, Electric Boat
	Institute for Religion and Peace
	Lockheed Martin - MS2, Syracuse
	Macquarie University
	Makani Power, Inc.
	MIT Humans and Automation Laboratory

(Academia and Industry	MIT Lincoln Laboratory
*continued***)**	Monterey Bay Aquarium Research Institute (MBARI)
	NAVPRO Consulting LLC
	Neptune Minerals
	Netherlands Defence Academy (NLDA), Eindhoven University of Technology (TU/e), School of Innovation Sciences: Philosophy & Ethics, TNO and Delft University of Technology
	Northrop Grumman
	Odyssey Marine Exploration
	Rockwell Collins, Inc.
	Raytheon
	SAIC, Inc.
	Sonalysts, Inc
	Spatial and Spectral Research
	Tech Associates, LLC
	Tethered Air, Inc.
	University of New Brunswick
	Unmanned Vehicle Systems Consulting, LLC

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LIST OF REFERENCES

Department of the Navy (2011*). Department of the Navy Unmanned Systems Goals*. Released as an attachment to UNSECNAV Work Memorandum, 1 February 2011. Last accessed 19 December 2011 at http://www.nps.edu/research/cruser/CRUSER_Letter_of_Marque.pdf

Department of Defense (2011). *Unmanned Systems Integrated Roadmap FY2011-2036*. Reference Number: 11-S-3613.

Rothal, J. and A. Davis (2011). *A Sampling of NPS Theses and Reports on UxS*, produced by the Dudley Knox Library, August 2011. Last accessed 21 December 2011 at https://wiki.nps.edu/display/CRUSER/Historical+Completed+Thesis%2C+Project+Work